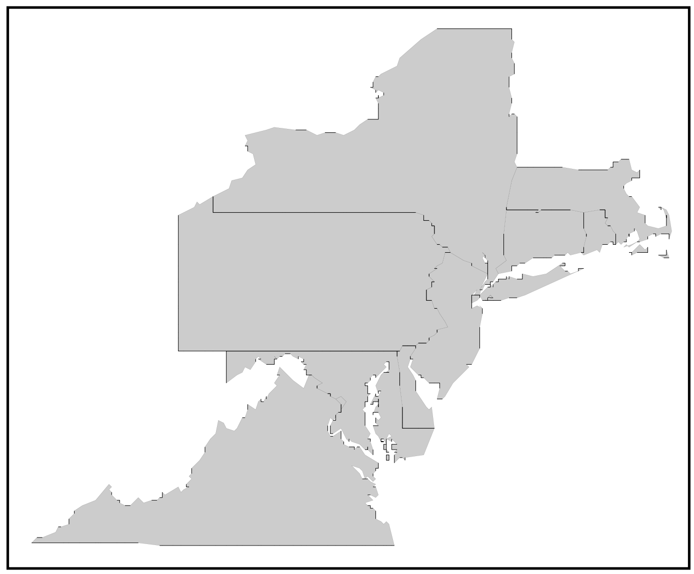
NOAA's Estuarine Eutrophication Survey

Volume 2: Mid-Atlantic Region



March 1997

Office of Ocean Resources Conservation and Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The National Estuarine Inventory

The National Estuarine Inventory (NEI) represents a series of activities conducted by NOAA's Office of Ocean Resources Conservation and Assessment (ORCA) since the early 1980s to define the nation's estuarine resource base and develop a national assessment capability. Over 120 estuaries are included (Appendix 3), representing over 90 percent of the estuarine surface water and freshwater inflow to the coastal regions of the contiguous United States. Each estuary is defined spatially by an estuarine drainage area (EDA)—the land and water area of a watershed that directly affects the estuary. The EDAs provide a framework for organizing information and for conducting analyses between and among systems.

To date, ORCA has compiled a broad base of descriptive and analytical information for the NEI. Descriptive topics include physical and hydrologic characteristics, distribution and abundance of selected fishes and invertebrates, trends in human population, building permits, coastal recreation, coastal wetlands, classified shellfish growing waters, organic and inorganic pollutants in fish tissues and sediments, point and nonpoint pollution for selected parameters, and pesticide use. Analytical topics include relative susceptibility to nutrient discharges, structure and variability of salinity, habitat suitability modeling, and socioeconomic assessments.

For a list of publications or more information about the NEI, contact C. John Klein, Chief, Physical Environments Characterization Branch, at the address below.

The Estuarine Eutrophication Survey

ORCA initiated the Estuarine Eutrophication Survey in October 1992. The goal is to comprehensively assess the scale and scope of nutrient enrichment and eutrophication in the NEI estuaries (see above) and to build a foundation of data that can be used to formulate a national response. The Survey is based, in part, upon a series of workshops conducted by ORCA in 1991-92 to facilitate the exchange of ideas on eutrophication in U.S. estuaries and to develop recommendations for conducting a nationwide survey. The survey process involves the systematic acquisition of a consistent and detailed set of qualitative data from the existing expert knowledge base (i.e., coastal and estuarine scientists) through a series of surveys, site visits, and regional workshops.

The original survey forms were mailed to over 400 experts in 1993. The methods and initial results were evaluated in May 1994 by a panel of NOAA, state, and academic experts. The panel recommended that ORCA proceed with a regional approach for completing data collection, including site visits with selected experts to fill data gaps, regional workshops to finalize and reach consensus, and regional reports on the results. The Mid-Atlantic regional workshop was held in January 1995; this document, Volume 2, is the regional report. The South Atlantic regional workshop was held in February 1996; the regional report, Volume 1, was completed in September 1996.

Site visits, regional workshops, and regional reports will be completed for the Gulf of Mexico, North Atlantic, and West Coast in 1997. A national assessment report of the status and health of the nation's estuaries will be developed from the survey results. In addition, an "indicator" of ecosystem health will also be published. Both national products will require one or more workshops to discuss and reach consensus on the methods proposed for conducting these analyses. ORCA also expects to recommend a series of follow-up activities that may include additional and/or improved water-quality monitoring, and case studies in specific estuaries for further characterization and analysis.

For publications or additional information, contact Suzanne Bricker, Project Manager, at the address below.

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ORCA Organization

The Office of Ocean Resources Conservation and Assessment (ORCA) is one of four line offices of the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service. ORCA provides data, information, and knowledge for decisions that affect the quality of natural resources in the nation's coastal, estuarine, and marine areas. It also manages NOAA's marine pollution programs. ORCA consists of three divisions and a center: the Strategic Environmental Assessments Division (SEA), the Coastal Monitoring and Bioeffects Assessment Division (CMBAD), the Hazardous Materials Response and Assessment Division (HAZMAT), and the Damage Assessment Center (DAC), part of NOAA's Damage Assessment and Restoration Program.

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Acknowledgments

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Contents

Introduction

This section presents an overview of how the Estuarine Eutrophication Survey is being conducted. It includes a statement of the problem, a summary of the project objectives, and a discussion of the project's origins and methods. A diagram illustrates the project process, and a table details the data being collected. The section closes with a brief description of the remaining tasks. For additional information, please see the inside front cover of this report.

About This Report

This report presents the results of ORCA's Estuarine Eutrophication Survey for 22 estuaries of the Mid-Atlantic region of the United States. It is the second in an expected series of five regional summaries (South Atlantic (NOAA, 1996), Mid-Atlantic, Gulf of Mexico, North Atlantic, and West Coast). A national report on the overall project results is also planned. The Survey is a component of ORCA's National Estuarine Inventory (NEI)—an ongoing series of activities that provide a better understanding of the nation's estuaries and their attendant resources (see inside front cover).

The report is organized into five sections: Introduction, Regional Overview, References, Estuary Summaries and Regional Summary. It also includes three appendices. The Introduction provides background information on project objectives, process, and methods. The Regional Overview presents a summary of findings for each parameter, and includes a regional map as well as maps illustrating the results for selected parameters. Next are the Estuary Summaries—one-page summaries of Survey results for each of the 22 Mid-Atlantic estuaries. Each page includes a narrative summary, a salinity map, a table of key physical and hydrologic information, and a matrix summary of data results. The Regional Summary displays existing parameter conditions and their spatial coverage across the region. Appendix 1 lists the regional experts who participated in the survey. Appendix 2 presents the references suggested by workshop participants as useful background material on the status and trends of nutrient enrichment in Mid-Atlantic estuaries.Appendix 3 presents a complete list of NEI estuaries.

The Problem

Between 1960-2010, the U.S. population has increased, and is projected to continue to increase, most significantly in coastal states (Culliton et al., 1990). This influx of people is placing unprecedented stress on the Nation's coasts and estuaries. Ironically, these changes threaten the quality of life that many new coastal residents seek. One of the most prominent barometers of coastal environmental stress is estuarine water quality, particularly with respect to nutrient imputs.

Coastal and estuarine waters are now among the most heavily fertilized environments in the world (Nixon et al., 1986). Nutrient sources include point (e.g., wastewater treatment plants) and nonpoint (e.g., agriculture, lawns, gardens) discharges. These inputs are known to have direct effects on water quality. For example, in extreme conditions, excess nutrients can stimulate excessive algal blooms that can lead to increased metabolism and turbidity, decreased dissolved oxygen, and changes in community structure—a condition described by ecologists as eutrophication (Day et al., 1989; Nixon, 1995; NOAA, 1989). Indirect effects can include impacts to commercial fisheries, recreation, and even public health (Boyton et al., 1982; Rabalais and Harper, 1992; Rabalais, 1992; Pearl, 1988; Whitledge and Pulich, 1991; NOAA, 1992; Burholder et al., 1992a; Cooper, 1995; Lowe et al., 1991; Orth and Moore, 1984; Kemp et al., 1983; Stevenson et al., 1993; Burkholder et al., 1992b; Ryther and Dunstun, 1971; Smayda, 1989; Whitledge, 1985; Nixon, 1983).

Reports and papers from workshops, panels, and commissions have consistently identified nutrient enrichment and eutrophication as increasingly serious problems in U.S. estuaries (National Academy of Science, 1969; Ryther and Dunstan, 1971; Likens, 1972; NOAA, 1991; Frithsen, 1989; Jaworski, 1981; EPA, 1995.). These conclusions are based on numerous local and regional investigations into the location and severity of nutrient problems, and into the specific causes. However, evaluating this problem on a national scale, and formulating a meaningful strategy for improvements, requires a different approach.

Objectives

The Estuarine Eutrophication Survey will provide the first comprehensive assessment of the temporal scale, scope, and severity of nutrient enrichment and eutrophication-related phenomena in the Nation's major estuaries. The goal is not necessarily to define one or more estuaries as eutrophic. Rather, it is to systematically and accurately characterize the scale and scope of eutrophication-related, water-quality parameters in over 100 U.S. estuaries. The project has four specific objectives:

1. To assess the existing conditions and trends, for the base period 1970 to present, of estuarine eutrophication parameters in 129 estuaries of the contiguous United States;

2. To publish results in a series of regional reports and a national assessment report;

3. To formulate a national response to identified problems; and

4. To develop a national "indicator" of estuarine health based upon the survey results.

ORCA also expects to recommend a series of follow-up activities that may include additional and/or improved water-quality monitoring, and case studies in specific estuaries for further characterization and analysis.

Methods

The topic of estuarine eutrophication has been receiving increasing attention recently in both the scientific literature (Nixon, 1995) and in the activities of coastal resource management agencies. In the United States, investigators have generated thousands of data records and dozens of reports over the past decade that document seasonal and annual changes in estuarine water quality, primary productivity, and inputs of nutrients. The operative question for this project is how to best use this knowledge and information to characterize these parameters for the contiguous United States.

Preparing for a national survey

To answer this question, ORCA conducted three workshops in 1991-92 with local and regional estuarine scientists and coastal resource managers. Two workshops, held at the University of Rhode Island's Graduate School of Oceanography in January 1991 (Hinga et al., 1991), consisted of presentations by invited speakers and discussions of the measures and effects associated with nutrient problems. The purpose was to facilitate the exchange of ideas on how to best characterize eutrophication in U.S. estuaries and to consider suggestions for the design of ORCA's proposed data collection survey. A third workshop, held in April 1992 at the Airlie Conference Center in Virginia, focused specifically on developing recommendations for conducting a nationwide survey.

Given the limited resources available for this project, it was not practical to try to gather and consolidate the existing data records. Even if it were possible to do so, it would be very difficult to merge these data into a comprehensible whole due to incompatible data types, formats, time periods, and methods. Alternatively, ORCA elected to systematically acquire a consistent and detailed set of qualitative data from the existing expert knowledge base (i.e., coastal and estuarine scientists) through a series of surveys, interviews, and regional workshops.

Identifying the Parameters and Parameter Characteristics

To be included in the Survey, a parameter had to be (1) essential for accurate characterization of nutrient enrichment; (2) generally available for most estuaries; (3) comparable among estuaries; and (4) based upon existing data and/or knowledge (i.e., no new monitoring or analysis required). Based upon the workshops described above and additional meetings with experts, 17 parameters were selected (Table 1).

The next step was to establish response ranges to ensure discrete gradients among responses. For example, the survey asks whether nitrogen is high, medium, or low based upon specific thresholds (e.g., High ≥ 1 mg/l, Medium ≥ 0.1 < 1 mg/l, low > 0 <0.1 mg/l, or unknown). The ranges were determined from nationwide data and from discussions with eutrophication experts. The thresholds used to classify ranges are designed to distinguish conditions among estuaries on a national basis, and may not distinguish among estuaries within a region.

Temporal Framework: Existing Conditions and Trends

For each parameter, information is requested for existing conditions and recent trends. Existing conditions describe maximum parameter values observed over a typical annual cycle (e.g., normal freshwater inflow, average temperatures, etc.). For instance, for nutrients, ORCA collected information characterizing peak concentrations observed during the annual cycle, such as those associated with spring runoff and/or turnover. For chlorophyll *a*, ORCA collected information on peak concentrations that are typically reached during an algal bloom period. Ancillary information is also requested to describe the timing and duration of elevated concentrations (or low levels in the case of dissolved oxygen). This information is collected because all regions do not show the same periodicity, and, for some estuaries, high concentrations can occur at any time depending upon conditions.

For some parameters, such as nuisance and toxic algal blooms, there is no standard threshold concentration that causes problems. In these cases, a parameter is considered a problem if it causes a detrimental impact on biological resources. Ancillary descriptive information is also collected for these parameters (Table 1).

	PARAMETERS	EXISTING CONDITIONS (maximum values observed over a typical annual cycle)	TRENDS (1970 - 1995)
ALGAL CONDITIONS	**CHLOROPHYLL *A***	• Surface concentrations: Hypereutrophic (>60 µg chl-a/l) High (>20, ≤60 µg chl-a/l) Medium (>5, ≤20 µg chl-a/l) Low (>0, ≤5 µg chl-a/l) • Limiting factors to algal biomass (N, P, Si, light, other) • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Concentrations[3,4] • Limiting factors • Contributing factors[5]
ALGAL CONDITIONS	**TURBIDITY**	• Secchi disk depths: High (<1m), Medium (1≥m, ≤3m), Low (>3m), Blackwater area • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Concentrations[3,4] • Contributing factors[5]
ALGAL CONDITIONS	**SUSPENDED SOLIDS**	• Concentrations: Problem (significant impact upon biological resources) No Problem (no significant impact) • Months of occurrence, Frequency of occurrence[2]	(no trends information requested)
ALGAL CONDITIONS	**NUISANCE ALGAE** **TOXIC ALGAE**	• Occurrence Problem (significant impact upon biological resources) No Problem (no significant impact) • Dominant species • Event duration (Hours, Days, Weeks, Seasonal, Other) • Months of occurrence, Frequency of occurrence[2]	• Event duration[3,4] • Frequency of occurrence[3,4] • Contributing factors[5]
ALGAL CONDITIONS	**MACROALGAE** **EPIPHYTES**	• Abundance Problem (significant impact upon biological resources) No Problem (no significant impact) • Months of occurrence, Frequency of occurrence[2]	• Abundance[3,4] • Contributing factors[5]
NUTRIENTS	**NITROGEN**	• Maximum dissolved surface concentration: High (≥1 mg/l), Medium (≥0.1, <1 mg/l), Low (≥0, < 0.1 mg/l) • Spatial coverage[1], Months of occurrence	• Concentrations[3,4] • Contributing factors[5]
NUTRIENTS	**PHOSPHORUS**	• Maximum dissolved surface concentration: High (≥0.1 mg/l), Medium (≥0.01, <0.1 mg/l), Low (≥0, < 0.01 mg/l) • Spatial coverage[1], Months of occurrence	• Concentrations[3,4] • Contributing factors[5]
DISSOLVED OXYGEN	**ANOXIA (0 mg/l)** **HYPOXIA (>0≤2 mg/l)** **BIOL. STRESS (>2≤5 mg/l)**	• Dissolved oxygen condition Observed No Occurrence • Stratification (degree of influence): (High, Medium, Low, Not a factor) • Water column depth: (Surface, Bottom, Throughout water column) • Spatial coverage[1], Months of occurrence, Frequency of occurrence[2]	• Min. avg. monthly bottom dissolved oxygen conc.[3,4] • Frequency of occurrence[3,4] • Event duration[3,4] • Spatial coverage[3,4] • Contributing factors[5]
ECOSYSTEM / COMMUNITY RESPONSE	**PRIMARY PRODUCTIVITY**	• Dominant primary producer: Pelagic, Benthic, Other	• Temporal shift • Contributing factors[5]
ECOSYSTEM / COMMUNITY RESPONSE	**PLANKTONIC COMMUNITY**	• Dominant taxonomic group (number of cells): Diatoms, Flagellates, Blue-green algae, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
ECOSYSTEM / COMMUNITY RESPONSE	**BENTHIC COMMUNITY**	• Dominant taxonomic group (number of organisms): Crustaceans, Molluscs, Annelids, Diverse mixture, Other	• Temporal shift • Contributing factors[5]
ECOSYSTEM / COMMUNITY RESPONSE	**SUBMERGED AQUATIC VEG.** **INTERTIDAL WETLANDS**	• Spatial coverage[1]	• Spatial coverage[3,4] • Contributing factors[5]

NOTES

(1) SPATIAL COVERAGE (% of salinity zone): High (>50, ≤100%), Medium (>25, ≤50%), Low (>10, ≤25%), Very Low (>0, ≤10%), No SAV / Wetlands in system

(2) FREQUENCY OF OCCURRENCE: Episodic (conditions occur randomly), Periodic (conditions occur annually or predictably), Persistent (conditions occur continually throughout the year)

(3) DIRECTION OF CHANGE: Increase, Decrease, No trend

(4) MAGNITUDE OF CHANGE: High (>50%, ≤100%), Medium (>25%, ≤50%), Low (>0%, ≤25%)

(5) POINT SOURCE(S), NONPOINT SOURCE(S), OTHER

Table 1: *Project parameters and characteristics.*

Trends information is requested for characterization of the direction, magnitude, and time period of change for the past 20 to 25 years. In cases where a trend has been observed, ancillary information is requested about the factors influencing the trend.

Spatial Framework

A consistently applied spatial framework was also required. ORCA's National Estuarine Inventory (NEI) was used (see inside front cover). For the survey, each parameter is characterized for three salinity zones as defined in the NEI (tidal fresh 0-0.5 ppt, mixing 0.5-25 ppt, and seawater >25 ppt). Not all zones are present in all NEI estuaries; thus, the NEI model provides a consistent basis for comparisons among these highly variable estuarine systems.

Reliability of Responses

Finally, respondents were asked to rank the reliability of their responses for each parameter as either highly certain or speculative inference, reflecting the robustness of the data upon which the response is based. This is especially important given that responses are based upon a range of information sources from statistically tested monitoring data to general observations. The objective is to exploit all available information that can provide insight into the existing and historic conditions in each estuary, and to understand its limitations.

The survey questions were reviewed by selected experts and then tested and revised prior to initiating the national survey. Salinity maps, based upon the NEI salinity zones, were distributed with the survey questions for orientation. Updates and/or revisions to these maps were made as appropriate.

Collecting the Data

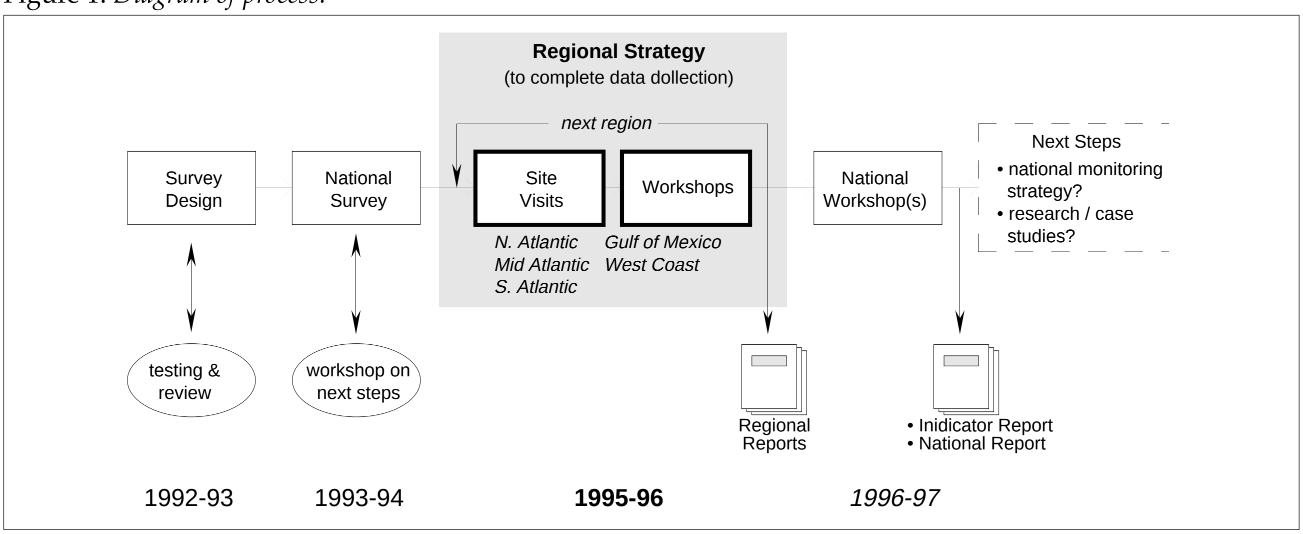
Over 400 experts and managers agreed to participate in the initial survey. Survey forms were mailed to the experts, who then mailed in their responses. The response rate was approximately 25 percent, with at least one response for 112 of the 129 estuaries being surveyed.

The initial survey methods and results were evaluated in May 1994 by a panel of NOAA, state, and academic eutrophication experts. The panel recommended that ORCA continue the project and adopt a regional approach for data collection involving site visits to selected experts to fill data gaps and revise salinity maps, regional workshops to finalize and reach consensus on the responses to each question (including salinity maps), and regional reports on the results. The revised strategy was implemented in the summer of 1994, starting with the 22 estuaries of the Mid-Atlantic region (Figure 1).

Estuaries are targeted for site visits based upon the completeness of the data received from the original mailed survey forms. The new information is incorporated into the project data base and summary materials are then prepared for a regional workshop.

Workshop participants are local and regional experts (at least one per estuary representing the group of people with the most extensive knowledge and insight about an estuary). In general, these individuals have either filled out a survey form and/or participated in a site visit. Preparations include sending all regional data to participants prior to the workshop. Participants are also encouraged to bring to the workshop relevant data and reports. At the workshop, at least two workgroups are established based upon geography.

Figure 1: *Diagram of process.*



The survey data and salinity maps for each estuary are then carefully reviewed. ORCA staff facilitate the discussions and record the results. At the close of the workshop, participants are asked to identify "critical" references such as reports and other publications that describe nutrient enrichment in one or more of the region's estuaries.

Workshop results are summarized for each estuary and mailed to workshop participants for review. The data are then compiled for presentation in a regional report that is also reviewed by participants prior to publication. The regional process, from site visits to publication of a regional report, takes approximately six months to complete. Some tasks are conducted concurrently.

Next Steps

Site visits, regional workshops, and regional reports are in progress for the Gulf of Mexico, North Atlantic, and West Coast (Figure 1). A national assessment report of the status and health of the nation's estuaries will be developed from the survey results. The regional results and final national data base will be available over the Internet through ORCA's Web site. Formulation of a national response to estuarine nutrient enrichment, and the development of a national "indicator" on coastal ecosystem health, will require one or more workshops to reach consensus on the methods and products resulting from these analyses. This work is currently scheduled for 1997. ORCA is funding a series of small contracts with regional experts to provide additional technical support for these tasks.

Regional Overview

This section presents an overview of the survey results. It begins with a brief introduction to the regional geography and a summary of how the results were compiled. Narrative summaries are then presented for each parameter in four subsections: Algal Conditions, Nutrients, Dissolved Oxygen, and Ecosystem/Community Response. Figures include a regional map showing the location of 22 Mid-Atlantic estuaries, a summary of probable-months-of-occurrence by parameter, four maps illustrating existing conditions for selected parameters, and a summary of recent trends by estuary for selected parameters.

The Setting: Regional Geography

The Middle Atlantic coastal province includes 22 major estuarine systems and encompasses more than 7,790 mi^2 of water surface area (Figure 2). The region is part of the Atlantic Coastal Plain called the Embayed Section; most of the area is submerged and joined to the Continental Shelf (Hunt, 1967). It consists of an irregular shoreline with wide sandy beaches and extensive coastal and barrier island formations. For this report, the region is divided into four subregions: the Southern New England Coast, New York Bight, Delmarva Shore/Delaware Bay, and the Chesapeake Bay (Beccasio, 1980). The Southern New England Coast extends from Cape Cod, Massachusetts to Montauk Point, New York, including Long Island Sound. The New York Bight spans the coastline from Montauk Point south to Cape May, New Jersey. Similar in physiography to the New York Bight, the Delmarva Shore includes the coastline from Cape May to Cape Charles, Virginia. The Chesapeake Bay includes the mainstem of the Bay and eight tributaries.

Southern New England Coast

The Southern New England Coast contains five estuarine systems and subsystems encompassing approximately 1,895 mi^2 of water surface area. This northernmost subregion was largely affected by historic episodes of glacial advance and retreat, and is now char-

Highlights of Regional Results

(Note: Tidal fresh = 5%, Mixing = 44%, Seawater = 51% of regional surface area (7790 mi^2))

Chlorophyll *a*

Hypereutrophic concentrations (>60 ug/l) are observed periodically in 9 of 22 estuaries, affecting 15-31% of the regional estuarine area; 11-22% of the tidal fresh zone, 20-40% of the mixing zone, no observations in the seawater zone. High or greater concentrations (>20 μg/l) are observed periodically in 20 estuaries, and occur in up to 36% of the regional estuarine area. These elevated concentrations occur in the summer to early fall with several estuaries also having winter occurrences. Declining trends were observed in 2 estuaries, increases in 7, no trend in 11, and trends are unknown in 2 estuaries.

Toxic Algae Blooms

Toxic algal blooms are reported to occur in 2 of 22 estuaries. These blooms have been noted in May and September in tributary embayments of western Gardiners Bay. In Long Island Sound, blooms occur episodically for days to weeks during summer over a very small area. There was no trend in the frequency of occurrence of toxic blooms for 12 estuaries, and trends were unknown for 10 estuaries.

Nitrogen

High nitrogen concentrations (>1.0 mg/l) have been observed in 14 of 22 estuaries. These concentrations are observed over 37-72% of the tidal fresh zone, and 9-19% of the mixing zone. Only two estuaries report high concentrations in the seawater zone (Delaware Inland Bays and Hudson River/Raritan Bay). Concentrations are reported to have increased in 3 estuaries, decreased in 6 estuaries and shown no trend in 10 estuaries. The trends for 2 estuaries are unknown.

Phosphorus

High phosphorus concentrations (>0.1 mg/l) were reported in 10 of 22 estuaries. These concentrations occur over 5-9% of the tidal fresh zone, 12-24% of the mixing zone, and 2-3% of the seawater zone, though spatial coverages for some estuaries are unknown so the coverage may be larger. Concentrations have increased in 4 estuaries, decreased in 8 estuaries, shown no trend in 7 estuaries, and are unknown for 3 estuaries.

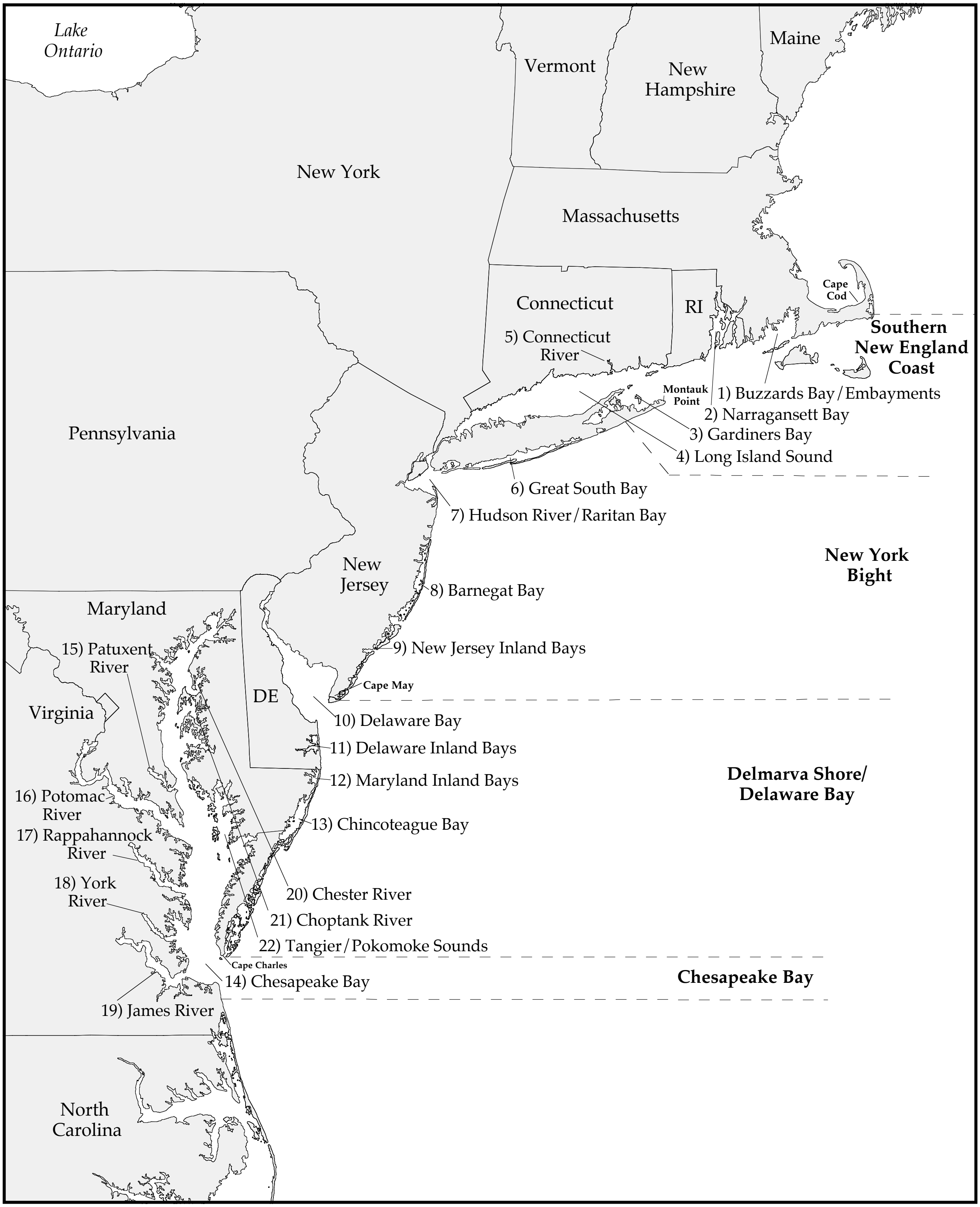
Hypoxia

During the summer months, periodic occurrences of hypoxia in bottom waters are observed in 13 of 22 estuaries over 10-20% of the regional estuarine surface area. Hypoxia was observed over 0-1% of the tidal fresh zone, 14-28% of the mixing zone and 8-15% of the seawater zone. For 8 of the 13 estuaries, water column stratification was reported to be a major influence. Spatial coverage of hypoxia has increased for 3 estuaries, decreased for 3 estuaries, remained the same for 10 estuaries, and are unknown for 6 estuaries.

Anoxia

During summer months, periodic occurrences of anoxia in bottom waters are observed in 11 of 22 estuaries over 6-13% of the regional estuarine area. These occurrences were observed over 0-3% of the seawater zone, 13-26% of the mixing zone, and <1% of the tidal fresh zone. For 9 of the 11 estuaries, water column stratification was reported to be a significant influence. The spatial coverage of anoxic events has increased in 2 estuaries, decreased in 2 estuaries, remained the same for 10 estuaries, and are unknown for 8 estuaries.

Figure 2: *Regional map of Mid-Atlantic showing four subregions and 22 estuaries.*



acterized by large island features and coastal plain formations. Elevated ridges such as Cape Cod, Long Island and Martha's Vineyard are topped with glacial drift deposits. Major coastal features include two large embayments (Buzzards Bay and Gardiners Bay) and Long Island Sound. These estuaries generally contain high salinities due to significant tidal mixing and openness to the Atlantic Ocean. Freshwater inflow is dominated by groundwater and, to a lesser extent, discharge from the Connecticut, Housatonic and Blackstone rivers. Depths average approximately 32 feet and are generally deeper than other systems in the region.

New York Bight

The New York Bight contains four major estuarine systems (~640 mi^2 of surface area) spanning the coastline of Long Island and New Jersey. The area is dominated by wide, sandy beach complexes and extensive barrier islands paralleling the present shoreline. The coastal plain portion of New Jersey consists mainly of swampy, alluvial flats as far west as the Fall Line. Extensive salt marshes are also predominant throughout the area. Tides are a dominant influence on water column mixing, primarily near the estuarine inlets. However, for Great South Bay, water column mixing is more influenced by winds. The Hudson River estuary is hydrographically distinct because of its dominant riverine influence. Within the New York Bight, freshwater inflow sources include the Hudson River and smaller coastal-plain-derived rivers (such as the Mullica River in New Jersey) as well as groundwater (as in Great South Bay).

Delmarva Shore/Delaware Bay

The coastline of the Delmarva Shore contains four estuarine systems (~990 mi^2 of surface area) and is dominated by a series of barrier islands, dune complexes and wide, sandy beaches. Alluvial flats extend as far west as the Fall Line. Extensive salt marshes are also predominant throughout the area. Tides are a dominant influence on water column mixing, primarily near estuarine inlets. Wind plays a major role in the short-term salinity structure and circulation. With the exception of Delaware Bay, freshwater inflow is minimal, and a vertically homogeneous salinity pattern persists throughout much of the year. Delaware Bay is hydrographically distinct in this characterization because of freshwater dominance from the Delaware River.

Chesapeake Bay

The Chesapeake Bay and surrounding tributaries comprise the southernmost portion of the Middle Atlantic region. This large, drowned river coastline contains nine major estuarine systems with a combined estuarine surface area of 4,278 mi^2. The Chesapeake Bay is a hydrographically dynamic area largely influenced by the rivers on both its eastern and western shores. The eastern shore consists of intertwined marsh systems with a series of marsh islands throughout. In the freshwater-dominated western side of the bay, salinities are generally lower and more stratified. Both western and eastern shores are somewhat protected from high-energy ocean influences (Beccasio, 1980). The Susquehanna, Potomac and James rivers are the major freshwater sources.

About the Results

The survey results are organized into four sections: Algal Conditions, Nutrients, Dissolved Oxygen, and Ecosystem Response. Each section contains a general overview followed by more detailed summaries for each parameter. This material is based on the individual estuary summaries presented later in this report. Regional patterns and anomalies are highlighted and existing conditions and trends are reviewed. Probable months of occurrence by parameter and by salinity zone are presented in Figure 3 (page 9). Regional maps summarizing existing conditions for selected parameters are presented in Figure 4 (page 11). A summary of recent trends for all parameters is presented in Figure 5 (page 14).

Data Reliability

As described in the introduction, participants were asked to rank the reliability of their responses as either highly certain or speculative inference. Over 90 percent of the responses are highly certain. Where relevant, speculative inferences are noted in the narrative below and on the estuary summaries that follow. A highly certain response is based upon temporally and spatially representative data from long-term monitoring, special studies, or literature. A speculative inference is based upon either very limited data or general observations. When respondents could not offer even a speculative inference, the value was recorded as "unknown".

Algal Conditions

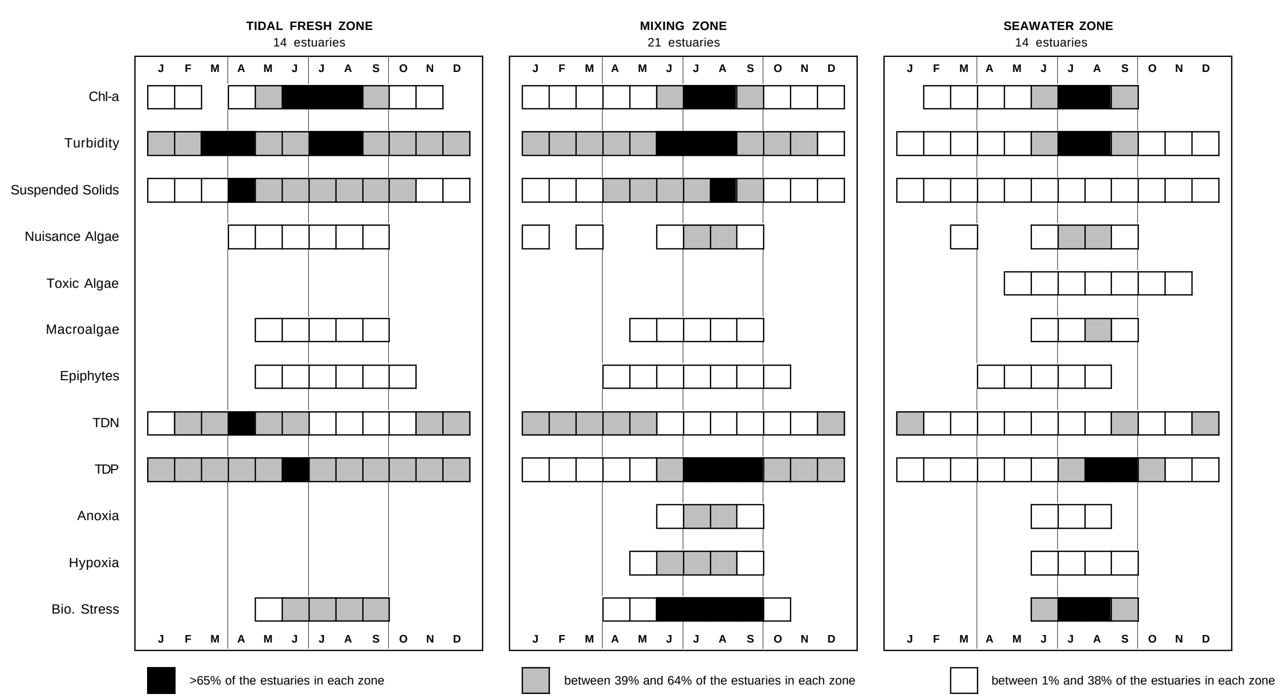
Algal conditions were characterized by existing conditions (maximum values observed over a typical annual cycle) and trends for chlorophyll *a*, turbidity, suspended solids, nuisance and toxic algae, macroalgal abundance, and epiphyte abundance (Table 1, page 3). Medium or greater concentrations of chlorophyll *a* (>5 μg/l) were reported for 70 percent of the region's tidal fresh zone surface area, 64 percent of the mixing zone, and 26 percent of the seawater zone. Hypereutrophic concentrations of chlorophyll *a* (>60 μg/l) were reported to occur almost entirely in the tidal fresh and mixing zones (21 and 40 percent of zone surface areas, respectively), with less than 0.5 percent of the seawater zone affected. Medium to High turbidity conditions (secchi disk depths of < 3 meters) occur over a larger percentage of the tidal fresh zone (67 percent) than the mixing or seawater zones (47 and 42 percent, respectively). Suspended solids were reported to have impacts on biological resources (e.g., submerged aquatic vegetation, filter feeders, etc.) in each of the estuaries in which medium to high turbidity concentrations occur. Nuisance algae impacts on biological resources were reported to occur in all of the subregions, but are concentrated primarily in the Southern New England Coast and New York Bight estuaries. In contrast, toxic algae impacts on biological resources are limited primarily to the seawater zone of two estuaries (Gardiners Bay and Long Island Sound). Macroalgal and epiphyte abundance impacts on resources are fairly evenly distributed among the salinity zones and throughout the region, with macroalgae impacts occurring in 10 estuaries and epiphyte impacts in seven estuaries.

Chlorophyll a

Hypereutrophic concentrations of chlorophyll *a* (>60 μg/l) were reported in 9 of 22 estuaries in the Mid-Atlantic region, occurring in up to 19 percent of the region's estuarine surface area. High or greater concentrations (>20 μg/l) were reported in all but two estuaries (Chincoteague Bay, York River) and occur in up to 36 percent of the region's estuarine surface area. The spatial extent of high or greater conditions was unknown in parts of six estuaries; therefore, the extent could be larger. Where conditions were reported as high to hypereutrophic, they occur periodically, except in Gardiners Bay and New Jersey Inland Bays, where they occur episodically. These concentrations occur primarily in the summer to early fall, with several estuaries also having winter occurrences. Medium or greater concentrations (>5 μg/l) of chlorophyll *a* were reported to occur in at least one salinity zone in all 22 estuaries of the Mid-Atlantic Region.

Figure 3: *Probable months of occurrence by parameter and by salinity zone (average).*

This figure illustrates the probable months, over a typical annual cycle, for which parameters are reported to occur at their maximum value. The black tone represents months where <u>*maximum values*</u> *occur in at least 65 percent of Mid-Atlantic estuaries for a particular salinity zone. For example, tidal fresh zones occur in 14 estuaries; therefore, a black tone indicates a maximum value was recorded in 10 or more estuaries. Similarly, for the mixing zone, black represents 14 or more estuaries, and for the seawater zone it represents 10 or more estuaries. Gray represents months where maximum values occur in 39 to 64 percent of the estuaries in that salinity zone, and unshaded boxes (white) represent months where maximum values occur between 1 and 38 percent of the estuaries in that zone. "Months-of-occurrence" data were not collected for Ecosystem/Community Response parameters (i.e., primary productivity, planktonic community, benthic community, and SAV).*



Increasing trends (circa 1970-1995) in chlorophyll *a* concentrations were reported in at least one salinity zone in five of the nine Chesapeake systems, and also in Buzzards Bay and New Jersey Inland Bays. Decreasing trends were observed in at least one salinity zone in the Potomac River and Maryland Inland Bays. There were no chlorophyll *a* concentration trends in nine estuaries, and trends were reported as unknown in two. Trends information was based partly on speculative inference in five estuaries.

Turbidity

Medium to High turbidity conditions (secchi disk depths of < 3 meters) were reported in at least one zone of all 22 Mid-Atlantic estuaries, covering 45 percent of the region's estuarine surface area. The spatial extent of medium to high concentrations was unknown in at least one zone for 13 estuaries; therefore, the extent could be much larger. High turbidity conditions (secchi disk depths of < 1 meter) were reported in all estuaries except Buzzards Bay and Narragansett Bay, encompassing 10 percent of the region's estuarine surface. However, since the spatial extent of high turbidity was unknown in 9 estuaries, the extent of the area covered could be much larger.

In the Southern New England Coast estuaries, medium or higher turbidity concentrations were reported to occur periodically during the summer (episodically for Barnegat Bay). These concentrations occur during the summer in Gardiners Bay and Long Island Sound, and December through January in Buzzards Bay embayments. The estuaries of the New York Bight and Delmarva region are also typified by periodic summer occurrences of medium or higher turbidity concentrations, with summer and winter occurrences in Hudson River/Raritan Bays and Delaware Inland Bays. Additionally, high turbidity conditions can occur throughout the year in Delaware Bay and Maryland Inland Bays. In the Chesapeake Bay systems, medium or higher concentrations are reported to occur throughout the year, except in the Rappahannock and York Rivers, where these concentrations can occur periodically from March through September and February through May, respectively.

Since 1970, small decreases in turbidity concentrations are reported in parts of Long Island Sound, Potomac River, Choptank River, and Tangier/Pocomoke Sounds. In the Patuxent River, a high magnitude increase from 1960 through 1984 was reported, and prior to the 1970s, increases in the Chesapeake mainstem and Potomac River were also recorded. No increases or decreases were reported for 13 other Mid-Atlantic estuaries, and trends were unknown for 5 estuaries.

Suspended Solids

Suspended solids were reported as impacting biological resources in 20 of the 22 Mid-Atlantic estuaries. Problem conditions were reported as episodic for five of the estuaries, and of these, New Jersey Inland, Barnegat, and Great South Bays are reported as wind-driven conditions. Impacts from suspended solids in the remaining 15 estuaries are reported to occur periodically.

From the Southern New England Coast through the Delmarva Shore, resource impacts from suspended solids were reported to occur periodically during the summer, with Long Island Sound, Delaware Inland Bays and Maryland Inland Bays having both summer and winter impacts. In the Chesapeake Bay systems, resource impacts were reported as typically occurring from around April through October, and all year in the Potomac River. Conditions reported for Long Island Sound and Connecticut River were based on speculative inference. Trends information was not collected for suspended solids.

Nuisance Algae

Nuisance algae were reported to have significant impacts on biological resources in 13 of the 22 Mid-Atlantic estuaries. These conditions were reported for all of the Southern New England Coast and New York Bight estuaries except for Buzzards Bay. Nuisance algae events in these subregions were reported to occur during the summer, with Long Island Sound and Hudson River/Raritan Bay having both summer and winter occurrences. The events in most of the estuaries of the Southern New England Coast and New York

Uniqueness of the Chesapeake Bay

The Chesapeake Bay is one of the most complex, productive, and studied estuaries in the world. It is the largest estuary in North America, with a surface area of 4,278 square miles (about the size of Connecticut) and a watershed that reaches into six states. The Bay's complexity is due to its unusual length (over 200 miles) and shallowness (average depth 24 ft), which make it one of the few embayments able to accommodate one semidiurnal tidal wave at all times. The Bay's tremendous productivity is attributed to the many habitats in the water and along the marshy coastline, and to the accumulation of sediments and nutrients brought in from the major tributaries. Recent declines in productivity have been attributed to human impacts on its ecosystem. Fortunately because this estuary is so heavily studied, these problems were recognized early, and numerous investigations into possible solutions are under way.

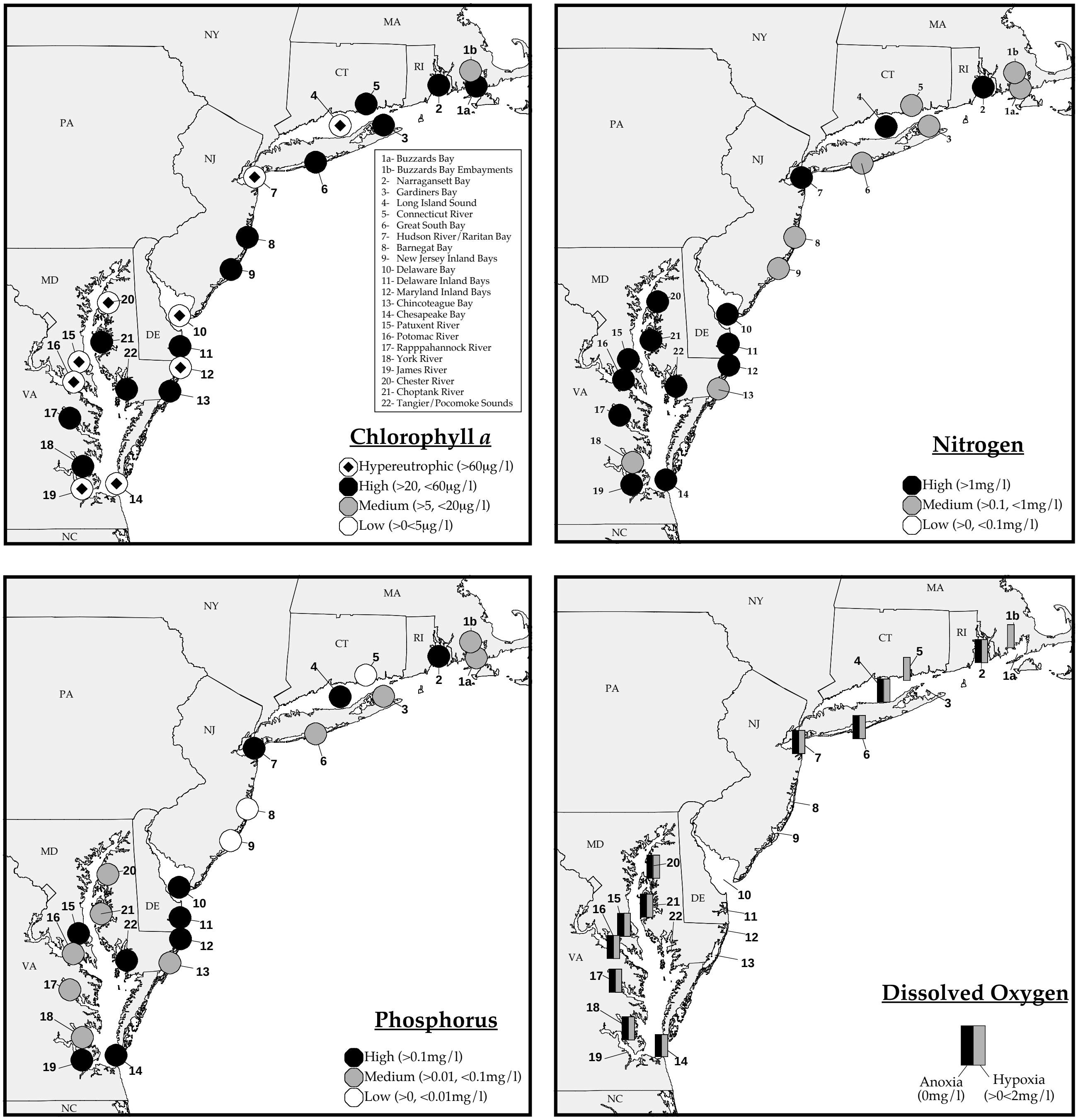


Figure 4: *Existing conditions for chlorophyll a, nitrogen, phosphorus, and dissolved oxygen. Symbols indicate that an existing condition(s) (e.g., hypereutrophic for chlorophyll a, anoxia and/or hypoxia for dissolved oxygen) was reported in at least a portion of one salinity zone of an estuary at some time during a typical annual cycle.Symbols do not necessarily represent existing conditions across an entire estuary. For a more complete review of individual estuaries, turn to the estuary summaries beginning on page 20.*

Bight were reported to be days to weeks in duration, but can be seasonal in Barnegat, Great South and Gardiners Bays. Nuisance blooms in these subregions were reported as occurring predictably, except in Gardiners, Great South, and New Jersey Inland Bays, where the occurrences of bloom events are more episodic in nature. Nuisance species reportedly are *Heterosigma*, *Prorocentrum*, *Aureococcus anophagefferens*, *Skeletonema costatum*, *Gymnodinium*, *Phaeocystis*, *Nanochloris atomus* and some diatom species.

In the Delmarva subregion, resource impacts from nuisance blooms were reported to occur only in Delaware Inland Bays and a small portion (tidal fresh zone) of Delaware Bay. In Delaware Bay the blooms reportedly occur during April and May and are short in duration (days). In Delaware Inland Bays nuisance algae events were reported as more seasonal in nature, occurring July through September. Nuisance algae reported to occur in this subregion are *microcystis*, turbidity-tolerant diatoms, and other unidentified green and blue-green algae.

In the Chesapeake Bay system, only the Patuxent, Potomac, and Choptank Rivers were reported to have resource impacts from nuisance blooms. The blooms were reported as having weeks to seasonal durations during the summer, with the Patuxent River also having winter occurrences. Nuisance algae reported to occur in these three rivers are *Gymnodinium*, *Katodinium rotundatum*, *Prorocentrum minimum*, *Microcystis aeruginosa*, *Anabaena*, *Oscillatoria*, and other unidentified dinoflagellates.

There were no trends reported in the duration or frequency of occurrence of nuisance algae events in 15 Mid-Atlantic estuaries during the past quarter-century (ca. 1970-95). Four estuaries (Narragansett Bay, Long Island Sound, New Jersey Inland Bays, and Patuxent River) were reported to have increases in either duration or frequency of nuisance algae events (or both); however, the Patuxent River trends have recently become stable. The Potomac River has had decreases in duration or frequency of nuisance algae events. Great South Bay and Gardiners Bay are difficult to categorize due to the episodic nature of "brown tide" blooms over the last 11 years. Trends were based on speculative inference in three estuaries.

Toxic Algae

Resource impacts from the toxic algae *Alexandrium tamarensis* were reported to occur episodically, lasting for days to weeks during May through September in Long Island Sound. This bloom has also been noted in tributary embayments of western Gardiners Bay during the spring and fall, with minimal resource impact because of the areas affected. Additionally, one bloom event of the toxic algae *Hematodinium perezi* was reported to occur in Maryland Inland Bays during July through September 1992.

Toxic algae trends are unknown for 9 of the 22 estuaries of the Mid-Atlantic. The other 13 were reported to have no trends in event occurrence, duration or frequency.

Macroalgal Abundance

Resource impacts from macroalgae were reported in at least one salinity zone of 10 estuaries in the Mid-Atlantic Region. These impacts were reported to occur periodically during the summer in eight of the estuaries, and episodically in Narragansett Bay and Choptank River. Macroalgal abundance information was not available for Connecticut River and Chincoteague Bay.

An increasing trend in macroalgal abundance was reported for Narragansett Bay, Gardiners Bay, Long Island Sound, and Tangier/Pocomoke Sounds. In the Gardiners Bay mixing zone, a decreasing trend in macroalgal abundance was reported from 1983 to 1989, and an increasing trend was reported from 1989 through 1994. The Gardiners Bay seawater zone and the lower tidal fresh zone of the Potomac River were reported to have declines in macroalgal abundance since 1970. Static conditions were reported in eight estuaries. Trends for nine estuaries were unknown.

Epiphyte Abundance

Resource impacts from epiphytes were reported in at least one salinity zone of seven estuaries throughout the Mid-Atlantic Region. Impacts were reported to occur periodically (episodic in Hudson River/Raritan Bays) from early to late summer. Epiphyte abundance information was unknown in five estuaries.

Trends for 12 Mid-Atlantic estuaries were unknown. Epiphyte abundance increased from 1970 through 1995 in Long Island and Tangier/Pocomoke Sounds. Increases were also reported for the Choptank River from 1950 through 1984, but abundance then declined, to a low extent, through 1995. There were no reported epiphyte abundance trends in seven estuaries.

Nutrients

Nutrient concentrations in the Mid-Atlantic region were characterized by collecting information on existing conditions (maximum values observed over a typical annual cycle) and trends information for the maximum values observed for nitrogen and phosphorus over a typical annual cycle. The intent was to collect information for total dissolved nutrients because this form is what is available to phytoplankton. Unless specifically noted otherwise, nutrient information presented in this report refers to total dissolved nitrogen (TDN) and phosphorus (TDP), including the inorganic and organic forms.

Results indicate that medium and high concentrations of both nitrogen and phosphorus are pervasive in the Mid-Atlantic region. The known spatial extent of medium or greater concentrations of nitrogen range from about 36 percent in the seawater zone to about 40 percent in the mixing zone. The spatial extent of these concentrations of phosphorus range from about 26 percent in the tidal fresh zone to about 36 percent in the seawater zone.

Trends information indicate that in most estuaries, there is either no change, or a decreasing trend, in nutrient concentrations. Increasing trends in TDN or TDP have occurred in Buzzards Bay, Long Island Sound, Delaware Bay, Chesapeake Bay, and in select zones of two Chesapeake Bay tributaries (Figure 5, page 14).

Nitrogen

High nitrogen concentrations (≥ 1.0 mg/l) have been observed in 14 of 22 Mid-Atlantic estuaries (Figure 4). These observations were recorded primarily in the tidal fresh (up to 275 square miles or 72 percent of the regional tidal fresh zone) and mixing zones (up to 655 square miles or 21 percent of the regional mixing zone). Only the East River, Jamaica Bay/Fresh Kills, and Delaware Inland Bays reported high concentrations in the seawater zone (up to 8 square miles or 0.2 percent). Medium or higher nitrogen concentrations (≥ 0.1 - 1.0 mg/l) have been observed in 19 of the 22 Mid-Atlantic estuaries. Low nitrogen concentrations (> 0 - 0.1 mg/l) were not reported for any estuary.

No information for trends was reported for all or part of 6 of the 22 estuaries (Figure 5). Increases between 10 and 25 percent over the last two to 15 years were reported for portions of Buzzards Bay, Long Island Sound, and Chesapeake Bay, although this increase is speculative for Buzzards Bay and Chesapeake Bay. Decreases between 10 and 25 percent over the last 10 to 25 years were reported for Delaware Bay, Patuxent River, Chincoteague Bay (speculative), and portions of Tangier/Pocomoke Sounds and Maryland Inland Bays (speculative). Decreases of greater than 50 percent over the last 25 years were reported for portions of Gardiners Bay. In addition, decreasing TDN concentration was reported in the tidal fresh zone of the Hudson/Raritan estuary, although the magnitude of this decrease was unknown. All or portions of 14 of the 22 Mid-Atlantic estuaries had no trends reported in the concentrations of nitrogen over the last 25 years.

Phosphorus

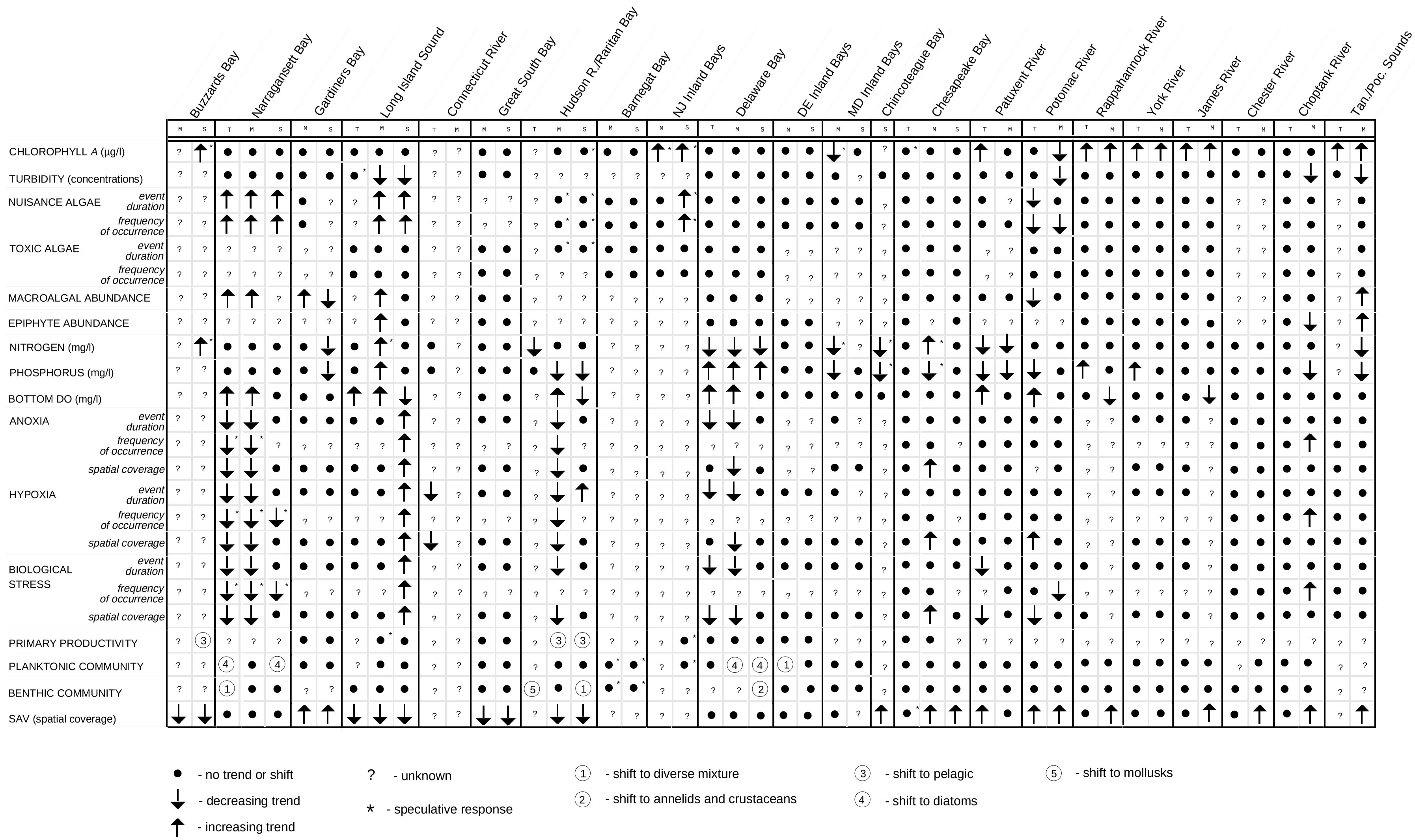
High phosphorus concentrations (≥ 0.1 mg/l) were reported in 10 of the 22 Mid-Atlantic estuaries. These concentrations were observed in all salinity zones. In the tidal fresh zone, high concentrations were reported in Narragansett Bay, Long Island Sound, and Delaware Bay, although spatial coverages were unknown. Based on coverage for the Patuxent River, James River, and Tangier/Pocomoke Sounds, up to 6 percent of the tidal fresh zone was reported to be high in TDP. In the mixing zone, Narragansett Bay, Long Island Sound, Delaware Inland Bays, and Maryland Inland Bays have unknown spatial coverages. The remaining known coverage for Hudson/Raritan Estuary and Chesapeake Bay comprise up to 26 percent of the mixing zone. Medium phosphorus concentrations (≥ 0.01 - 0.1 mg/l) were reported for 17 of the 22 Mid-Atlantic estuaries. Low phosphorus concentrations (> 0 - 0.1 mg/l) were reported in Barnegat Bay, New Jersey Inland Bays, and the tidal fresh zone of the Connecticut River.

No trends in phosphorus concentrations were reported for 6 of the 22 Mid-Atlantic estuaries (Figure 5). Increases between 10 and 25 percent over the last two to 25 years were reported to have occurred in portions of Long Island Sound, Delaware Bay, and the Rappahannock and York Rivers. The tidal fresh portion of Delaware Bay is the only area in the Mid-Atlantic in which a 50 to 100 percent increase in phosphorus concentrations was reported to have occurred over the last 25 years. Decreases of 50 to 100 percent were reported for portions of Gardiners Bay, Hudson/Raritan Bay (speculative), Patuxent River, and the Potomac River. In addition, Tangier/Pocomoke Sounds were reported to have a decrease in phosphorus concentrations by 25 to 50 percent, and all or portions of the Hudson/Raritan, Maryland Inland Bays, Chincoteague Bay, Chesapeake Bay, and Patuxent River showed decreases of 10 to 25 percent. Choptank River was reported as decreasing, but the magnitude was unknown.

Dissolved Oxygen

Dissolved oxygen concentrations were characterized by collecting information on existing conditions and trends for three conditions: anoxia (0 mg/l), hypoxia (>0 mg/l< 2 mg/l), and biological stress (>2 mg/l< 5 mg/l). Timing and location of these conditions in the water column (surface, bottom, throughout), and the influence of water column stratification (high, medium, low, not a factor) were also recorded. The spatial extent of each condition was also noted.

Figure 5: *Recent trends (1970 - present for most estuaries) for selected parameters by estuary by salinity zone (T, tidal fresh; M, mixing; S, seawater). All salinity zones are not present in all estuaries. Most of the 1,152 possible values are no trend (569). There are 91 decreasing trends, 79 increasing trends, and 401 unknowns. The remaining 12 responses display shifts in the primary productivity, planktonic community or benthic community. 37 values are based on speculative inferences. For a more complete listing of the trends parameters, see Table 1 on page 3.*



Highly variable concentrations of low dissolved oxygen were reported throughout the Mid-Atlantic region (Figure 4, page 11). Thirteen of 22 estuaries were reported to have anoxic/hypoxic levels at some point during the year. Anoxia/hypoxia were reported as periodic, primarily during the summer months, in most estuaries within the Southern New England Coast, northern New York Bight and Chesapeake Bay subregions. However, the spatial extent of these conditions was very low to low (0 to 25 percent). Only minor incidences of low dissolved oxygen were reported for the southern estuaries of the New York Bight and all of the Delmarva Shore. Water column stratification was reported to be a major factor in the expression of this condition for portions of the Southern New England Coast, northern New York Bight and the Chesapeake Bay estuaries.

Trends for minimum average monthly bottom concentrations of dissolved oxygen were reported as decreasing for four estuaries, increasing for six estuaries, and not changing for 10 estuaries.

Anoxia

Anoxic conditions were reported in 11 of 22 estuaries, representing approximately 13 percent of the total estuarine surface area (918 mi^2) (Figure 4). Anoxia was reported to occur in only one estuary in the New York Bight subregion (Jamaica Bay of the Hudson River/Raritan Bay), and no occurrences were reported in the Delmarva Shore estuaries. If anoxia was present, the spatial extent of this condition was generally reported to be very low (0 to 10 percent) to low (10 to 25 percent), except for the Chesapeake Bay mainstem and a small portion of Narragansett Bay, where it was reported as medium (25 to 50 percent). Anoxic conditions were reported in seven of nine estuaries within the Chesapeake Bay subregion, encompassing 876 mi^2 or 20 percent of the subregion.

Where anoxia was reported, water column stratification was identified as a major factor in the expression of the condition for all but two estuaries—Great South Bay and the Choptank River. Anoxic conditions were reported to occur mainly at the bottom of the water column. Anoxic events were reported as mostly periodic, beginning in June and ending in September.

Trends were known for 15 estuaries. Increasing trends in the frequency of occurrence of anoxic events were reported for two estuaries (Long Island Sound and Choptank River), a speculative decrease in frequency was reported for one estuary (Narragansett Bay), and five estuaries were reported as having no change in conditions. Long Island Sound and Patuxent River (1930-79 only) were reported to have an increase in the duration of anoxic events. Delaware Bay and Narragansett Bay were reported to have a decrease in the duration of events. Twelve estuaries had no change in conditions. The trends reported in spatial extent of anoxic events were similar to the trends in duration. The only exception was Chesapeake Bay, where an increase in the spatial extent of anoxic events was reported in the mixing zone (Figure 5).

Hypoxia

Hypoxic conditions of dissolved oxygen (>0mg/l < 2 mg/l) were reported in 13 of 22 Mid-Atlantic estuaries, representing approximately 20 percent of the region's estuarine surface area (1573 mi^2) (Figure 4). The spatial extent of these conditions was reported as medium (25 to 50 percent) for three estuaries, and very low (0 to 10 percent) or low (10 to 25 percent) for the remainder.

Water column stratification was reported as a major factor in the expression of hypoxic conditions for 8 of 13 estuaries. In each case, hypoxic events occurred at the bottom of the water column. Stratification was not a factor within Connecticut River and Great South Bay. Hypoxic events were reported as mostly periodic, beginning in June and ending in September.

Trends were reported for 17 estuaries. Increasing trends in the frequency of occurrence of hypoxic events were reported for two estuaries (Long Island Sound and Choptank River), a speculative decrease in frequency was reported for one estuary (Narragansett Bay), and five estuaries had no change in conditions. Long Island Sound and Hudson River/Raritan Bay were reported to have an increase in the duration of hypoxic events. Four estuaries were reported to have a decrease in the duration of events. Twelve estuaries had no change in conditions. The trends in spatial extent of hypoxic events were similar to the trends in duration. Exceptions were the Chesapeake Bay, Patuxent River (1930-79 only), and Potomac River, where an increase in the spatial extent of hypoxic events was reported, and Hudson Bay/Raritan River, where the trends were reported as stable. (Figure 5).

Biological Stress

Biologically stressful levels of dissolved oxygen (>2mg/l<5 mg/l) were reported in all Mid-Atlantic estuaries except the Connecticut River, representing approximately 37 percent of the region's estuarine surface area (2936 mi^2). A medium (25 to 50 percent) to high (50 to 100 percent) spatial extent of these conditions was predominant throughout many of the region's larger estuarine systems (e.g., Chesapeake Bay and Long Island Sound).

Water column stratification was reported to be a major factor in the expression of biologically stressed conditions when the spatial extent was either medium or high. These conditions were reported to be throughout the water column in 13 of 22 estuaries. Stressed events were reported as mostly periodic, beginning in June and ending in September, though some occurrences started as late as July in the Southern New England Coast.

Trends were known for 17 estuaries. Increasing trends in the frequency of occurrence of biologically stressful events were reported for two estuaries (Long Island Sound and Choptank River), a decrease in frequency was reported for two estuaries (Narragansett Bay and Potomac River), and four estuaries had no change in conditions. Long Island Sound was reported to have an increase in the duration of these events. Four estuaries were reported to have a decrease in the duration of events. Twelve estuaries had no change in conditions. The trends in spatial extent of these conditions were similar to the trends in duration. Exceptions were an increase in the mixing zone of the Chesapeake Bay, and a decrease in the tidal fresh zone of the Potomac River (Figure 5).

Ecosystem/Community Response

The responses of estuarine ecosystems to nutrient inputs were characterized by collecting information on the status and trends of four parameters: primary productivity, pelagic and benthic communities, and submerged aquatic vegetation (SAV). Information regarding primary productivity indicated that the region is dominated almost exclusively by pelagic communities. The dominant plankton community varied between diatoms in the spring, flagellates in the summer, and a diverse mixture of diatoms, flagellates and other plankton groups during the rest of the year. Annelids dominated the benthic community, followed by a diverse mixture of annelids, mollusks, and/or crustaceans. SAV was reported in all but two of the region's estuaries, primarily at a low or very low density. Little variation was reported for all four ecosystem parameters throughout the region or across salinity zones.

Information regarding historical shifts (ca. 1970-95) in the estuarine ecosystem indicated that the region is generally stable with regard to primary productivity and the plankton and benthic communities. Where shifts in dominance were reported, they occurred in only five estuaries, including shifts in two of the parameters in Narragansett Bay, Hudson River/Raritan Bay, and Delaware Bay. An increasing trend in SAV coverage was reported for nearly half of the region's estuarine area, mostly in the mixing zones of the Chesapeake Bay and its tributaries. A decreasing trend in coverage also was reported for a fourth of the region's estuarine area, primarily in the mixing and seawater zones.

Primary Productivity

Pelagic communities were identified as the dominant primary producer in one or more salinity zones in 10 of 23 Mid-Atlantic estuaries, representing 72 percent of the region's estuarine surface area, including 92 percent of the region's seawater zone. No other individual community was identified as a dominant primary producer; however, a diverse mixture of benthic and pelagic organisms was reported in all or parts of four estuaries (5 percent of the regional surface area). No information was available in the remaining parts of the region, including all eight tributaries of the Chesapeake Bay.

Temporal shifts in primary productivity, i.e., shifts in dominance from one primary producer to another, were reported as unknown in all or parts of 18 Mid-Atlantic estuaries (42 percent of the region's estuarine surface area). Where information was available, no shifts were reported, with the exception of the mixing and seawater zones of the Hudson River/Raritan Bay, and the seawater zone of the Buzzards Bay embayments, where primary productivity shifted from a diverse mixture of benthic and pelagic organisms to a community dominated exclusively by pelagic organisms. The factors contributing to these shifts were unknown.

Plankton Community

A seasonal variation was reported in the dominant (i.e., most abundant) plankton communities in the Mid-Atlantic region. Diatoms were identified as the dominant plankton group in parts of 8 of 22 estuaries (19 percent of the region's estuarine surface area) at all times of the year, but they were dominant in parts of 11 estuaries (54 percent of the area) for at least some parts of the year, primarily in the spring. Similarly, throughout the year, flagellates were identified as the dominant plankton group in parts of three estuaries (less than one percent of the regional estuarine surface area), but they were the most dominant group in parts of seven estuaries (41 percent of the area) for at least some portion of the year, particularly in the summer. Both plankton communities were reported to be distributed uniformly across each salinity zone, the only exception being that flagellates were reported in only one tidal fresh estuary (Maryland Inland Bays), comprising one percent of the region's tidal fresh zone. Most of the remaining area of the Mid-Atlantic region was reportedly dominated by a diverse mixture of diatoms, flagellates, and other plankton groups. Two reported exceptions were chlorophytes in the seawater zone of the New Jersey Inland Bays, and blue-green algae in the tidal fresh zone of the Patuxent River.

Shifts in plankton dominance, from one taxonomic group to another, were reported to occur in three Mid-Atlantic estuaries during the period 1970-95. Shifts were reported from blue-green algae to a diverse mixture of plankton groups in the mixing zone of the Delaware Inland Bays, and from a diverse mixture of plankton groups to diatoms in the mixing and seawater zones of the Delaware Bay. In Narragansett Bay, shifts were reported in the tidal fresh zone from blue-green algae to diatoms, and in the seawater zone, from flagellates to diatoms. Point and nonpoint sources were identified as the contributing factors to the shift in the Narragansett Bay seawater zone; however, factors contributing to shifts in other parts of the region were unknown. No shifts were reported in all or parts of 17 of 22 estuaries, representing 54 percent of the region's estuarine surface area.

Benthic Community

Annelids were identified as the dominant benthic community, in terms of abundance, in all or parts of 14 of 22 Mid-Atlantic estuaries, including 77 percent of the region's tidal fresh zone, 74 percent of the mixing zone, and 67 percent of the seawater zone. Most of the remaining area in the region was reportedly dominated by a diverse mixture of annelids, mollusks, and/or crustaceans. Two reported exceptions were mullusks, which were dominant in the tidal fresh zone of one estuary and the mixing zone of two estuaries, and crustaceans, which were dominant in the seawater zone of two estuaries.

Historical shifts (ca. 1970-95) in benthic community dominance, from one taxonomic group to another, were reported as unchanged in all or parts of 15 estuaries, including 77 percent of the region's tidal fresh zone, 81 percent of the mixing zone, and 67 percent of the seawater zone. Shifts in dominance were reported from annelids to a diverse mixture of benthic groups in the tidal fresh zone of Narragansett Bay and the seawater zone of Hudson River/Raritan Bay, and from annelids to mullusks in the tidal fresh zone of Hudson River/Raritan Bay. No contributing factors were reported for those shifts. Another shift, from a diverse mixture of benthic groups, including mullusks, to a community dominated by annelids and crustaceans, was reported in the seawater zone of Delaware Bay, and attributed to the parasitic oyster disease Dermo (*Perkinsus marinus*).

Submerged Aquatic Vegetation (SAV)

The presence of SAV was reported in at least one salinity zone in all Mid-Atlantic estuaries except Delaware Bay and Delaware Inland Bays, representing 82 percent (6,400 mi^2) of the region's estuarine area, including 99 percent of the New England subregion. SAV density (to depths of one meter below mean low water) was reported to be low (>10≤25 percent surface area) or very low (≤10 percent surface area) in 19 estuaries (63 percent of the regional estuarine area), including 14 of 21 tidal fresh estuaries. A medium density (>25≤50 percent surface area) was reported for the remaining areas of the Mid-Atlantic region, with the exception of the seawater zone of New Jersey Inland Bays, where a high density (>50 percent surface area) was reported.

The spatial coverage of SAV was reported to be increasing in 10 Mid-Atlantic estuaries (48 percent of the region's estuarine area), including parts of all Chesapeake Bay subsystems except the York River. Increases in coverage were generally reported in the mixing zone at low or medium magnitudes (0-50 percent change). The factors contributing to the increases were mostly unknown; however, improvements from point and nonpoint sources were reported for Patuxent River, Potomac River and the mainstem of the Chesapeake Bay. No changes in spatial coverage were reported in parts of 12 estuaries (21 percent of the region's estuarine area); however, in four of these systems no SAV was reported at the present time. Declining trends in coverage were reported in four estuaries, representing 25 percent of the region's estuarine area, primarily in the mixing and seawater zones. The declining trends generally occurred at a low or medium magnitude. A high magnitude decrease was reported for Hudson River/Raritan Bay, where the existing spatial coverage of SAV is very low in the seawater zone and no longer present in the mixing zone. The declines were attributed to wasting disease. Factors contributing to declining trends in other regional estuaries were point and nonpoint sources in the Central Buzzards Bay/Embayments and Long Island Sound, and brown tides in Great South Bay. The declining and subsequent increasing trends in SAV coverage in Gardiners Bay were also attributed to a brown tide event.

References

Beccasio, A. D., G.H. Weissberg, A.E. Redfield, R.L. Frew, W.M. Levitan, J.E. Smith, and R.E. Godwin. 1980. Atlantic Coast ecological inventory user's guide and information base. U.S. Fish and Wildlife Service. pp. 163.

Boynton, W.R., W.M. Kemp, and C.W. Keefe. 1982. A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production. In: V.S. Kennedy (ed.), Estuarine comparisons. New York City: Academic Press. pp. 69-90.

Burkholder, J.M., K.M. Mason, and H.B. Glasgow Jr. 1992a.Water-column nitrate enrichment promotes decline of eelgrass Zostera marina evidence from seasonal mesocosm experiments. Mar. Ecol. Prog. Ser. 81:163-178.

Burkholder, J.M., E.J. Noga, C.H. Hobbs, and H.B. Glasgow Jr. 1992b. New "phantom" dinoflagellate is the causative agent of major estuarine fish kills. Nature 358:407-410.

Cooper, S.R. 1995. Chesapeake Bay watershed historical land use: Impacts on water quality and diatom communities. Ecol. App. 5(3): 703-723.

Culliton, T.J., M.A. Warren, T.R. Goodspeed, D.G. Remer, C.M. Blackwell, and J.D. McDonough III. 1990. 50 years of population change along the nation's coasts 1960-2010. Coastal Trends Series report no. 2. Rockville, MD: National Oceanic and Atmospheric Administration, Strategic Assessment Branch. 41 p.

Day, J.W. Jr., C.A.S. Hall, W.M. Kemp, and A. Yanez-Arancibia. 1989. Estuarine ecology. New York City: John Wiley and Sons. 558 p.

Environmental Protection Agency (EPA). 1995. National nutrient assessment workshop proceedings. EPA 822-R-96-004.

Frithsen, J.B. 1989 (draft). Marine eutrophication: Nutrient loading, nutrient effects and the federal response. Fellow, American Association for the Advancement of Science / EPA Environmental Science and Engineering. 66 p.

Hinga, K.R., D.W. Stanley, C.J. Klein, D.T. Lucid, and M.J. Katz (eds.). 1991. The national estuarine eutrophication project: Workshop proceedings. Rockville, MD: National Oceanic and Atmospheric Administration and the University of Rhode Island Graduate School of Oceanography. 41 p.

Hunt, C.B. 1967. Physiography of the United States. San Francisco and London: W.H. Freeman and Company. pp. 480.

Jaworski, N.A. 1981. Sources of nutrients and the scale of eutrophication problems in estuaries. In: B.J. Neilson and L.E. Cronin (eds.), Estuaries and nutrients. Clifton, NJ: Humana Press. pp. 83-110.

Kemp, W.M., R.R. Twilley, J.C. Stevenson, W.R. Boynton, and J.C. Means. 1983. The decline of submerged vascular plants in upper Chesapeake Bay: Summary of results concerning possible causes. Mar. Tech. Soc. Journal 17(2):78-89.

Likens, G.E. 1972. Nutrients and eutrophication: The limiting nutrient controversy. Proceedings of a symposium on nutrients and eutrophication, W.K. Kellogg Biological Station, Michigan State University, Hickory Corners, MI, Feb. 11-12, 1971. Lawrence, KS: Allen Press, Inc., for the American Society of Limnology and Oceanography, Inc. 328 p.

Lowe, J.A., D.R.G. Farrow, A.S. Pait, S.J. Arenstam, and E.F. Lavan. 1991. Fish kills in coastal waters 1980-1989. Rockville, MD: NOAA Office of Ocean Resources Conservation and Assessment, Strategic Environmental Assessments Division. 69 p.

National Academy of Sciences (NAS). 1969. Eutrophication: Causes, consequences, correctives. Proceedings of an international symposium on eutrophication, University of Wisconsin, 1967. Washington, DC: NAS Printing and Publishing Office. 661 p.

National Oceanic and Atmospheric Administration (NOAA). 1996. NOAA's Estuarine Eutrophication Survey. Volume 1: South Atlantic Region. Silver Spring, MD: NOAA Office of Ocean Resources Conservation and Assessment. 50 p.

NOAA. 1992. Red tides: A summary of issues and activities in the United States. Rockville, MD: NOAA Office of Ocean Resources Conservation and Assessment. 23 p.

NOAA. 1991. Nutrient-enhanced coastal ocean productivity. Proceedings of a workshop, Louisiana Universities Marine Consortium, October 1991. Held in conjunction with NOAA Coastal Ocean Program Office. TAMU-SG-92-109. Galveston, TX: Texas A&M University Sea Grant Program. pp. 150-153.

NOAA. 1989. Susceptibility and status of East Coast estuaries to nutrient discharges: Albemarle/Pamlico Sound to Biscayne Bay. Rockville, MD: NOAA Office of Ocean Resources Conservation and Assessment. 31 p.

Nixon, S.W. 1995. Coastal marine eutrophication: A definition, social causes, and future concerns. Ophelia 41:199-219.

Nixon, S.W. 1983. Estuarine ecology: A comparative and experimental analysis using 14 estuaries and the MERl mesocosms. Final report to the U.S. Environmental Protection Agency, Chesapeake Bay Program, Grant No. X-003259-01. April 1993.

Nixon, S.W., C.D. Hunt, and B.N. Nowicki. 1986. The retention of nutrients (C,N,P), heavy metals (Mn, Cd, Pb, Cu), and petroleum hydrocarbons in Narragansett Bay. In: P. Lasserre and J.M. Martin (eds.), Biogeochemical processes at the land-sea boundary. Amsterdam: Elsevier Press. pp. 99-122.

Orth, R.J. and K.A. Moore. 1984. Distribution and abundance of submerged aquatic vegetation in Chesapeake Bay: An historical perspective. Estuaries 7:531-540.

Pearl, H.W. 1988. Nuisance phytoplankton blooms in coastal, estuarine and inland waters. Limnology and Oceanography 33:823-847.

Rabalais, N.N. 1992. An updated summary of status and trends in indicators of nutrient enrichment in the Gulf of Mexico. Prepared for the Gulf of Mexico Program, Technical Steering Committee, Nutrient Subcommittee, Stennis Space Center, MS. Publication No. EPA/800-R-92-004. 421 p.

Rabalais, N.N. and D.E. Harper Jr. 1992. Studies of benthic biota in areas affected by moderate and severe hypoxia. In: Nutrient-enhanced coastal ocean productivity. Proceedings of a workshop, Louisiana Universities Marine Consortium, October 1991. Held in conjunction with NOAA Coastal Ocean Program Office. TAMU-SG-92-109. Galveston, TX: Sea Grant Program, Texas A&M University. pp. 150-153.

Ryther, J.H. and W.N. Dunstan. 1971. Nitrogen and eutrophication in the coastal marine environment. Science 171:1008-1013.

Smayda, T.J. 1989. Primary production and the global epidemic of phytoplankton blooms in the sea: A linkage? In: E.M. Cosper, V.M. Bricelj, and E.J. Carpenter (eds.), Novel phytoplankton blooms: Causes and effects of recurrent brown tides and other unusual blooms. Coastal and Estuarine Series 35. Berlin: Springer-Verlag. pp. 449-483.

Stevenson, J.C., L.W. Staver, and K.W. Staver. 1993. Water quality associated with survival of submerged aquatic vegetation along an estuarine gradient. Estuaries 16(2):346-361.

Whitledge, T.E. 1985. Nationwide review of oxygen depletion and eutrophication in estuarine and coastal waters: Executive summary. (Completion report submitted to U.S. Dept. of Commerce.) Rockville, MD: NOAA, NOS. 28 p.

Whitledge, T.E. and W.M. Pulich Jr. 1991. Report of the brown tide symposium and workshop, July 15-16, 1991. Port Aransas, TX: Marine Science Institute, University of Texas. 44 p.

Estuary Summaries

This section presents one-page summaries on the status and trends of eutrophication conditions for the 22 Mid- Atlantic estuaries. The summary information is organized into four sections: algal conditions, nutrients, dissolved oxygen, and ecosystem/community responses. Each page also includes a salinity map depicting the spatial framework for which survey information was collected, selected physical and hydrologic characteristics, and a narrative overview of the survey information.

Salinity Maps. Salinity maps depict the estuary extent, salinity zones, and subareas within the salinity zones. Salinity zones are divided into tidal fresh (0.0-0.5 ppt), mixing (0.5-25.0 ppt), and seawater (>25.0 ppt) based on average annual salinity found throughout the water column. Subareas were identified by survey participants as regions that were either better understood than the rest of a salinity zone, or that behaved differently, or both. Each map also has an inset showing the location of the estuary and its estuarine drainage area (EDA) (see below).

Physical and Hydrologic Data. Physical and hydrologic characteristics data are included so that readers can better understand the survey results and make meaningful comparisons among the estuaries. The EDA is the land and water component of a watershed that drains into and most directly affects estuarine waters. The average daily inflow is the estimated discharge of freshwater into the estuary. Surface area includes the area from the head of tide to the boundary with other water bodies. Average depth is the mean depth from mid-tide level. Volume is the product of the surface area and the average depth.

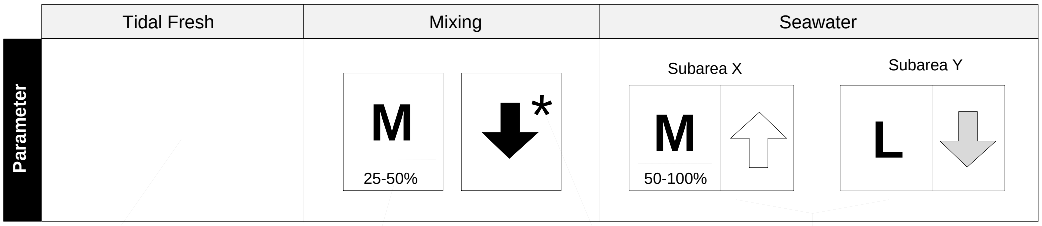
Survey Results. Selected data are presented in a unique format that is intended to highlight survey results for each estuary. The existing conditions symbols represent either the maximum conditions predominating one or more months in a typical year, or whether there are resource impacts due to bloom events. The trends (circa 1970-1995 unless otherwise stated) symbols indicate either the direction and magnitude of change in concentrations, or in the frequency of occurrence.

The four sections on each page include a text block to highlight additional information such as probable months of occurrence and periodicity for each parameter, limiting factors to algal biomass, nuisance and toxic algal species, nutrient forms, and degree of water column stratification.

Some parameters are not characterized by symbols on the estuary pages. These include macroalgal and epiphyte abundance, biological stress, minimum average monthly bottom dissolved oxygen trends, temporal shifts in primary productivity, benthic community shifts, intertidal wetlands, and planktonic community shifts. These parameters are described in the Regional Overview section (starting on page 6) and, where relevant, highlighted in the text blocks under each parameter section on the estuary pages.

See the next page for a key that explains the symbols used on the summary pages. See Table 1 on page 3 for complete details about the characteristics of each parameter.

Key to Symbols Used on Estuary Summaries

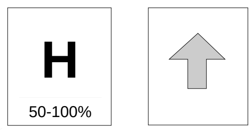


Salinity Zone Absent: if the salinity zone is not present in the estuary the entire box is left blank

Spatial Coverage: surface area over which condition occurs (not listed for nuisance/toxic algae or low/not observed conditions)

Reliability: indicates assessment made from speculative inferences

Salinity Zone Divided: salinity zones are often divided into subareas to account for unique characteristics



Existing Conditions

Concentrations

(Chl a, Turbidity, Nutrients, SAV)

E hypereutrophic
- chl-*a*: >60 µg/l

H high
- chl-*a*: >20, ≤60 µg/l
- turbidity: secchi <1m
- TDN: ≥1 mg/l
- TDP: ≥0.1 mg/l
- SAV >50, ≤100 % coverage

M medium
- chl-*a*: >5, ≤20 µg/l
- turbidity: secchi ≥1m, ≤3m
- TDN: ≥0.1, <1 mg/l
- TDP: ≥0.01, <0.1 mg/l
- SAV >25, ≤ 50 % coverage

L low
- chl-*a*: >0, ≤5 µg/l
- turbidity: secchi >3m
- TDN: >0, <0.1 mg/l
- TDP: >0, <0.01 mg/l
- SAV >10, ≤ 25 % coverage

VL very low
- SAV >0, ≤10 % coverage

NS no SAV in zone

B blackwater area

? unknown

Event Occurrences

(Nuisance/Toxic Algae, d.o.)

Y impacts on resources
- nuisance algae: impacts occur
- toxic algae: impacts occur

or

low d.o. is observed
- anoxia: 0 mg/l
- hypoxia: >0, ≤2 mg/l

N no resource impacts
- no nuisance algae impacts
- no toxic algae impacts

or

low d.o. not observed
- no anoxic events
- no hypoxic events

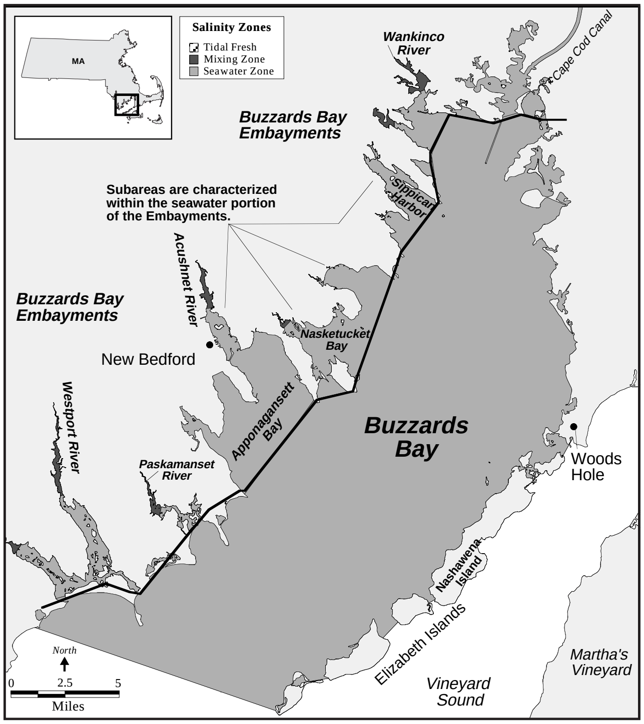
? unknown

Trends (circa 1970-1995)

(Concentrations or Frequency of Event Occurrences)

Direction of Change	Magnitude of Change
⬆ increase	⬆ high >50%, ≤100%
⬇ decrease	⇧ medium >25%, ≤50%
– – – no trend	⇧ low >0%, ≤25%
? unknown	⇧? magnitude unknown

Buzzards Bay



In Buzzards Bay, chlorophyll *a* concentrations are moderate to high, and turbidity is low to moderate. Biological resource impacts from nuisance and toxic algal blooms generally do not occur. Maximum nitrogen and phosphorus concentrations are reported as medium. Anoxia is not observed, but hypoxia is observed in the seawater embayments. Conditions within the mixing zone are mostly unknown.

Trends are unknown except in the seawater zone of Buzzards Bay where chlorophyll *a* and nitrogen are speculated to have increased since 1970. SAV is present in low amounts throughout the estuary and has decreased since 1970.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **601** Avg. Daily Inflow *(cfs)* **1,200**

	Estuary	TF	Mixing	Seawater: Buzzards Bay	Seawater: Embayments	Seawater: Embay. Subareas
Surface Area *(mi²)*	**203.0**	**0**	**2.2**	**196.0**	**4.8**	**n/a**
Average Depth *(ft)*	**33.8**	**0**	**13.9**	**34.1**	**15.3**	**n/a**
Volume *(billion cu ft)*	**191**	**0**	**0.8**	**188.0**	**2.1**	**n/a**

A glacial outwash dominated system consisting of the main bay and smaller coastal embayments. The Elizabeth Islands breach the main bay from Vineyard Sound to the south. Freshwater inflow from surficial sources is minimal with groundwater seepage dominating freshwater inputs into the bay. The main bay remains as seawater for the majority of the year and has a vertically homogeneous salinity structure. Tidal range is approximately 4 ft throughout the bay.

Algal Conditions

	Tidal Fresh	Mixing	Seawater: Buzzards Bay	Seawater: Embayments	Seawater: Embay. subareas
Chlorophyll *a*		? ?	M (?) ↑ *	M (50-100%) ?	H (0-10%) ?
Turbidity		? ?	L ?	L ?	M (0-10%) ?
Nuisance Algae		? ?	N ?		
Toxic Algae		? ?	N ?		

In the seawater zone, maximum chl-*a* concentrations occur periodically in late spring to summer, with a limiting factor of nitrogen. In the embayment subareas, maximum turbidity occurs throughout the year.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater: Buzzards Bay	Seawater: Embayments
SAV		L ↓	L ↓	L ↓

Primary production is dominated by the pelagic community, but historically was pelagic and benthic in parts of the seawater zone. The planktonic community is diverse; embayment benthic community is dominated by mollusks. SAV has decreased due to changes in point sources.

Nutrients

	Tidal Fresh	Mixing	Seawater: Buzzards Bay	Seawater: Embayments
Nitrogen		? ?	M (?) ↑ (?)	M (?) ?
Phosphorus		? ?	M (?) ?	M (?) ?

Elevated concentrations of TDN occur October to January; trends are associated with changes in point sources. Elevated concentrations of TDP occur July to October.

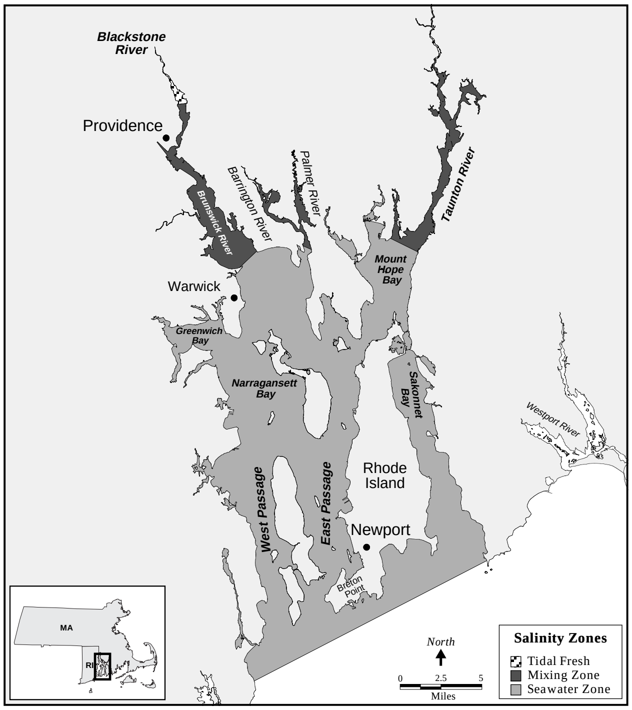
Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater: Buzzards Bay	Seawater: Embayments
Anoxia		N ?	N ?	N ?
Hypoxia		N ?	N ?	Y (10-25%) ?

Episodic occurrences of hypoxia occur during the summer in the bottom-waters of the embayment seawater zone.

Key on page 21

Narragansett Bay



In Narragansett Bay, chlorophyll *a* concentrations are moderate to high, and turbidity is moderate. Biological resources are impacted by nuisance algal blooms in all salinity zones. Nitrogen and phosphorus concentrations are high in the tidal fresh zone, and moderate to high in the mixing and seawater zones. Anoxic and hypoxic events are observed throughout the estuary, except in the seawater zone where anoxia is not observed.

No trends were reported for most conditions, however nuisance algal blooms are reported to have increased and occurrences of anoxia / hypoxia are reported to have decreased. SAV coverage is reported to be low in the seawater zone, and has disappeared from the tidal fresh and mixing zones.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,349** Avg. Daily Inflow *(cfs)* **3,200**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**165.0**	**3.0**	**20.0**	**142.0**
Average Depth *(ft)*	**30.2**	**17.2**	**16.9**	**32.4**
Volume *(billion cu ft)*	**141**	**1.4**	**9.4**	**130**

Includes Narragansett Bay and several smaller embayments. It receives the majority of freshwater from the Blackstone and Taunton rivers. Circulation affected largely by tidal mixing and wind currents. Narragansett Bay maintains a fairly homogeneous salinity structure. Ocean water intrudes further up the East Passage than in the West Passage. Tides range 3 ft at the mouth of the bay to approximately 5 ft near Warwick, Rhode Island.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*	M ?	---	H ?	---	M ?	---
Turbidity	M ?	---	M ?	---	M ?	---
Nuisance Algae	Y	↑ ?	Y	↑	Y	↑
Toxic Algae	N	---	N	---	N	---

Maximum chl-*a* concentrations occur periodically in late spring to summer. Light is limiting factor in tidal fresh and mixing zones, nitrogen in seawater zone. Highest turbidity occurs during summer. Nuisance *Heterosigma* blooms occur periodically during summer, with durations of less than a week.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	NS	---	NS	---	L	---

Primary production is dominated by the pelagic community. The planktonic community in tidal fresh and seawater zone is dominated by diatoms, and in the mixing zone by flagellates. The benthic community is a diverse mixture in the tidal fresh zone; annelids dominate in the mixing and seawater zones. SAV Disappeared in the tidal fresh and mixing zones between 1938 and 1951.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	H ?	---	M ?	---	M ?	---
Phosphorus	H ?	---	H ?	---	M ?	---

Elevated nutrient concentrations occur November to January.

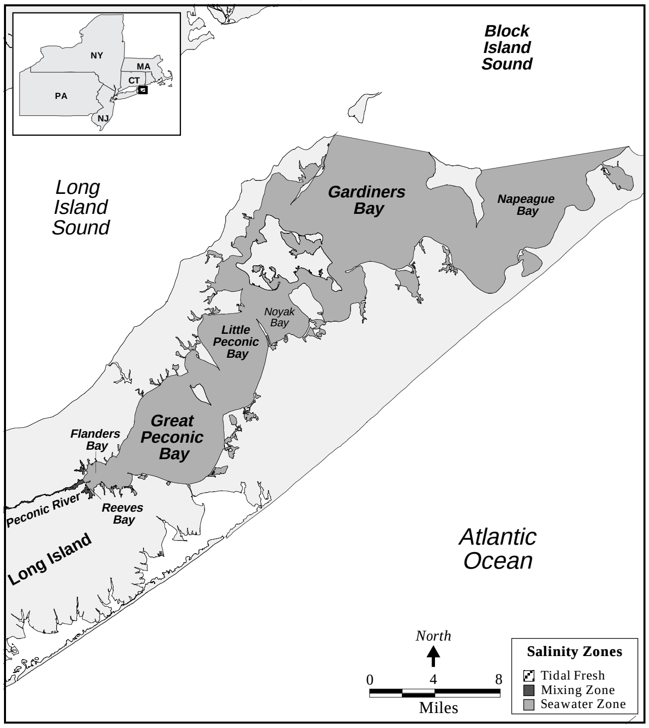
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	Y 25-50%	↓	Y 10-25%	↓	N	?
Hypoxia	Y 10-25%	↓	Y 10-25%	↓	Y	↓

Periodic anoxia / hypoxia occurs in bottom waters from June to September. Water column stratification plays a moderate role in development of these conditions. Event duration, frequency, and spatial coverages have all decreased due to changes in point sources.

Key on page 21

Gardiners Bay



In Gardiners Bay, chlorophyll *a* and turbidity concentrations are high in the mixing zone, and moderate to high in the seawater zone. Episodic nuisance and toxic algal blooms have impacted biological resources in both salinity zones. Maximum nitrogen and phosphorus concentrations are moderate. There are no observations of anoxia or hypoxia. The conditions are observed in both mixing and seawater zones.

Trends since 1970 are reported as stable or unknown except a high magnitude decline of nitrogen in Flanders Bay. SAV is present in limited amounts and has increased in recent years due to recovery from brown tides.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **459** Avg. Daily Inflow *(cfs)* **700**

	Estuary	Tidal Fresh	Mixing	Seawater: In General	Seawater: Flanders Bay
Surface Area *(mi²)*	197.0	0	0.02	195.3	2.5
Average Depth *(ft)*	20.2	0	4.0	20.2	3.4
Volume *(billion cu ft)*	110	0	.002	109.8	0.2

Part of the Long Island complex consisting of Gardiners Bay and several smaller embayments. The area is characteristic of glacial outwash deposits and freshwater input is generally dominated by groundwater sources. Minimal freshwater is supplied by the Peconic River. Salinity structure is essentially vertically homogeneous with tidal mixing and wind influences being significant forcing mechanisms on salinity structure. Tides range 2 ft near the entrance to Block Island Sound.

Algal Conditions

	Tidal Fresh	Mixing		Seawater: In General		Seawater: Flanders Bay	
Chlorophyll *a*		H (?)	---	M (50-100%)	---	H (0-10%)	---
Turbidity		H (?)	?	H (50-100%)	?		
Nusiance Algae		Y	?	Y	?		
Toxic Algae		?	?	Y	?		

Maximum chl-*a* concentrations occur episodically in summer, with a limiting factor of light in the mixing zone and nitrogen in the seawater zone. Highest turbidity occurs during summer in the mixing zone and all year in the seawater zone. Nuisance *Aureococcus* occurs in summer and toxic *Alexandrium* blooms have been noted in spring and fall.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		L	↑?	L	↑?

Primary production is dominated by the pelagic community. The planktonic community is a diverse mixture. SAV coverage has increased in recent years due to recovery from brown tides.

Nutrients

	Tidal Fresh	Mixing		Seawater: In General		Seawater: Flanders Bay	
Nitrogen		M (?)	---	M (50-100%)	---	M (50-100%)	↓
Phosphorus		M (?)	---	M (50-100%)	---	M (50-100%)	↓

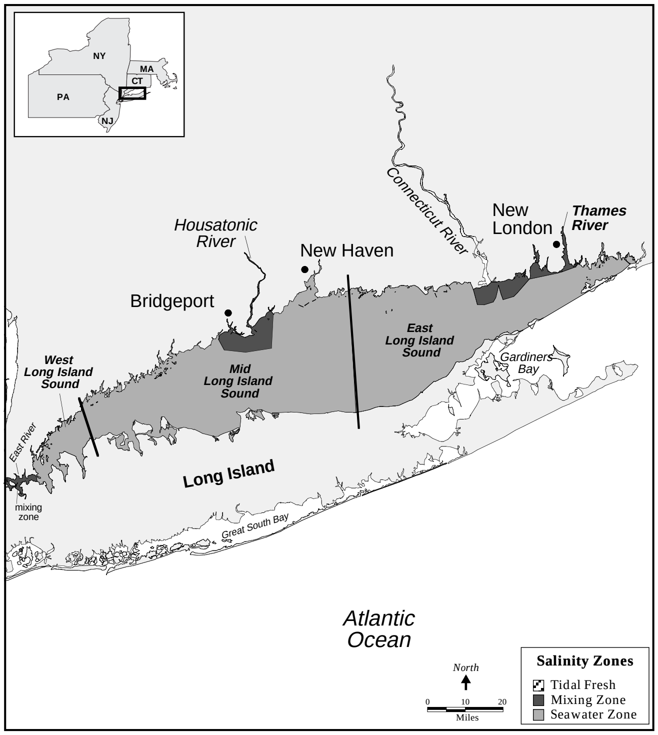
Elevated concentrations of TDP occur in the mixing zone during the summer and all year in the seawater zone. Decreases in nitrogen and phosphorus in Flanders Bay is due to reduction in number of duck farms in watershed.

Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	N	?
Hypoxia		N	?	N	?

Key on page 21

Long Island Sound



In Long Island Sound, chlorophyll *a* concentrations are high in the tidal fresh and mixing zones and there is a gradient of medium to hypereutrophic concentrations from the eastern to western seawater zone. Turbidity concentrations are moderate to high. Biological resources are impacted by nuisance algal blooms in all zones, and by toxic algal blooms in the seawater zone. Concentrations of nitrogen and phosphorus are reported as moderate to high. Anoxic events are observed in the seawater zone, and hypoxic events are observed in the mixing and seawater zones.

Trends vary from decreases in turbidity, to increases in nuisance algae, low dissolved oxygen events, and nutrients, to no recent trends in concentrations of chlorophyll *a*, and toxic algae. SAV concentrations are very low to low and have decreased.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (*mi2*) **7,336** Avg. Daily Inflow (*cfs*) **30,000**

	Estuary	Tidal Fresh	Mixing		Seawater		
			General	East R.	Western	Mid	Eastern
Surface Area (*mi²*)	1278.7	11.0	81.2	7.3	59.7	619.4	500.1
Average Depth (*ft*)	62.2	27.3	34.1	21.0	31.2	58	77
Volume (*billion cu ft*)	2218	8.4	77	4.2	52	1002	1074

An expansive, glacial outwash dominated estuarine system. Major freshwater inputs are from the Housatonic, Connecticut and the Thames rivers. Influence of the East River promotes a stratified salinity structure in the western sound especially in the spring runoff period. Salinity variability is less distinct in the eastern sound where salinities tend to be higher. Tidal range is approximately 4.2 ft in the southern sound to nearly 6 ft in the northern sound area.

Algal Conditions

	Tidal Fresh		Mixing		Seawater: Western		Seawater: Mid		Seawater: Eastern	
Chlorophyll *a*	H (?)	---	H (50-100%)	---	E (0-10%)	---	H (25-50%)	---	M (25-50%)	---
Turbidity	M (?)	---	H (50-100%)	↓	H (0-10%)	↓	M (50-100%)	↓	M (50-100%)	↓
Nuisance Algae	Y	?	Y	↑			Y	↑		
Toxic Algae	N	---	N	---			Y	---		

Maximum chl-*a* conc. occur periodically late spring/summer in tidal fresh, and early spring/summer in mixing and seawater zones. Limiting factor is nitrogen for tidal fresh and mixing, co-limiting with silica and light in seawater. Nuisance *Skeletonema* blooms periodically in mixing zone, nuisance *Phaeocystis*, *Prorocentrum*, and *Gymnodinium* with toxic *Alexandrium* blooms periodically in seawater zone in early spring/summer, with durations less than a week. Low magnitude increases in chl-*a* from 1945-1980 in seawater zone.

Ecosystem/Community Responses

	Tidal Fresh		Mixing: In General		Mixing: East River		Seawater	
SAV	L	↓	L*	↓	NS	↓	VL	↓

Primary productivity is dominated by pelagic and benthic communities in tidal fresh and mixing zones, and pelagic in seawater zone. Planktonic community is predominately diatoms and flagellates; benthic community is dominated by annelids. SAV decrease attributed to point/non-point sources and wasting disease.

Nutrients

	Tidal Fresh		Mixing: In General		Mixing: East River		Seawater	
Nitrogen	H (?)	---	H (?)	---	H (50-100%)	↑*	M (50-100%)	---
Phosphorus	H (?)	---	H (?)	---	H (?)	↑	M (50-100%)	---

Elevated conc. of TDN occur July to October. Elevated conc. of TDP occur April to June in the tidal fresh zone, and August to October in the mixing and seawater zones. Increase in East River from 1992-94.

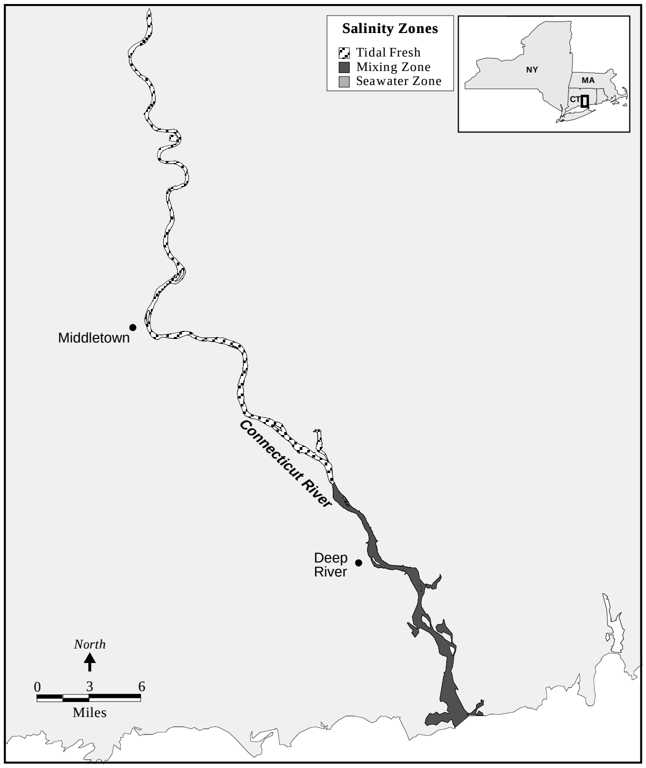
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	?	Y (0-10%)	↑
Hypoxia	N	?	Y (25-50%)	?	Y (25-50%)	↑

Periodic bottom-water hypoxia events occur from June to September. In August of 1987, anoxia was observed in the bottom waters of the seawater zone. Event duration, frequency, and spatial coverages have all increased due to changes in point and non-point sources, and an increased occurrence of stratification.

Key on page 21

Connecticut River



In the Connecticut River, concentrations of chlorophyll *a* are high, and turbidity is moderate. Occurrences of nuisance algal blooms are reported to impact biological resources. In the tidal fresh zone, nitrogen concentrations are moderate, and phosphorus concentrations are low. Episodic hypoxic events are also reported in the tidal fresh zone.

Most trends are recorded as unknown. SAV coverage is low with unknown trends.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,112** Avg. Daily Inflow *(cfs)* **21,000**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**20.0**	**18.0**	**2.0**	**0**
Average Depth *(ft)*	**12.5**	**12.8**	**9.9**	**0**
Volume *(billion cu ft)*	**7.0**	**6.4**	**0.6**	**0**

This riverine subsystem to Long Island Sound is the most significant source of freshwater input to the middle and eastern sound. Salinity structure near the mouth displays a salt wedge classification. During spring runoff, salinities tend to be lower in the eastern sound due to high freshwater discharge from the Connecticut River. Moderate stratification occurs during mean river stages. The offshore river plume boundary is formed by a frontal layer where density and other properties change abruptly. Tidal range is approximately 3 ft near the mouth.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
Chlorophyll *a*	H ?	?	H ?	?	
Turbidity	?	?	M ?	?	
Nuisance Algae	Y	?	Y	?	
Toxic Algae	N	?	N	?	

Chl-*a* maximums occur periodically during late summer. Nuisance blooms of *Chlorella* occur in the tidal fresh zone during summer for durations of a week.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater
SAV	L	?	L	?	

Annelids are the dominant benthic community in the mixing zone.

Nutrients

	Tidal Fresh		Mixing		Seawater
Nitrogen	M ?	– – –	?	?	
Phosphorus	L	– – –	?	?	

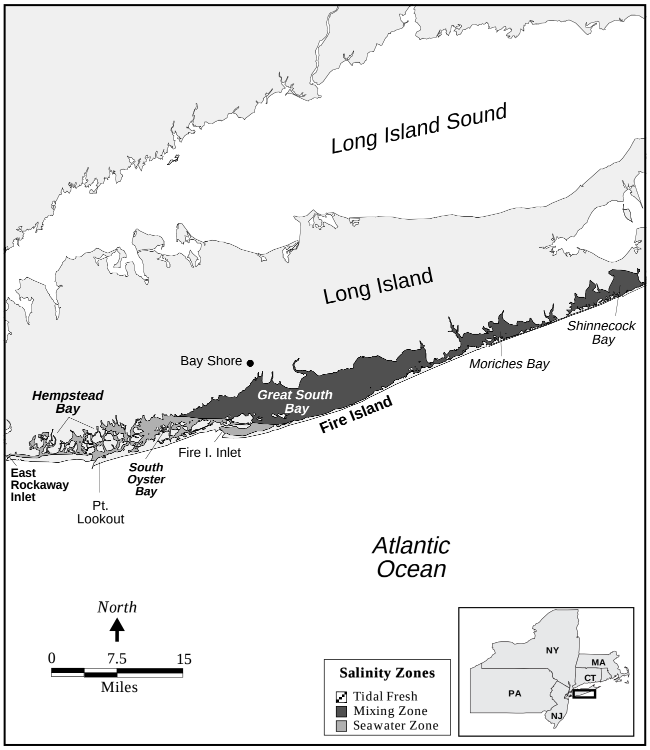
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater
Anoxia	?	?	N	?	
Hypoxia	Y 10-25%	?	N	?	

Episodic hypoxic events occur in the tidal fresh zone (months of occurrence are unknown). Although trends of event frequency are unknown, duration of events and spatial coverage have decreased due to changes in point sources.

Key on page 21

Great South Bay



In Great South Bay, chlorophyll *a* concentrations are moderate to high, and turbidity is high. Nuisance algae blooms are reported as having an impact on biological resources. Nitrogen and phosphorus concentrations are medium throughout the year. In the mixing zone, anoxic and hypoxic events are reported to occur periodically.

Trends are reported as stable except for unknown trends of nuisance algae blooms and dissolved oxygen conditions. SAV coverage is low with moderate decreases due to brown tides.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **822** Avg. Daily Inflow *(cfs)* **700**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	**151.0**	**0**	**115.5**	**33.4**
Average Depth *(ft)*	**8.9**	**0**	**7.7**	**10.1**
Volume *(billion cu ft)*	**38**	**0**	**17**	**21**

A narrow, bar-built estuary containing a series of interconnected embayments and inlets. Glacial outwash deposits are characteristic of the area and freshwater input is dominated by groundwater sources and small coastal streams. Tides range approximately 2.5 ft near the inlets (East Rockaway Inlet ~4.0 ft). Salinity structure is vertically homogeneous throughout the the estuary.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*			H 25-50%	---	M ?	---
Turbidity			H ?	---	H ?	---
Nuisance Algae			Y	?	Y	?
Toxic Algae			N	---	N	---

Chl-*a* and turbidity maximums occur periodically in early summer in both zones, with a limiting factor of light for chl-*a*. During the summer, nuisance *Aureococcus* blooms occur episodically with a duration of a week.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			L	↓	L	↓

Primary productivity is dominated by pelagic and benthic communities that are diverse. SAV coverage has decreased due to brown tides in mixing zone, and in seawater zone due to blooms of *Ulva lactuca* (Hempstead Bay).

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen			M 50-100%	---	M 50-100%	---
Phosphorus			M 50-100%	---	M 50-100%	---

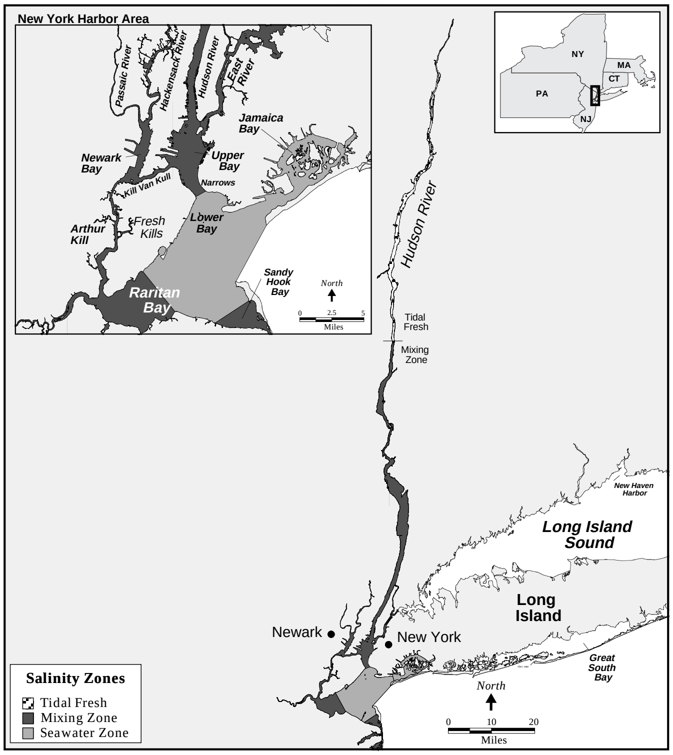
Elevated nutrient concentrations occur throughout the year.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			Y 0-10%	?	N	?
Hypoxia			Y 0-10%	?	N	?

From July to September, periodic anoxic/hypoxic events occur throughout the water column in the tidal creeks of the mixing zone.

Hudson River/Raritan Bay



In the Hudson River / Raritan Bay, maximum chlorophyll *a* concentrations range from moderate to hypereutrophic, and maximum turbidity and nutrient concentrations are moderate or high. Nuisance algal blooms impact biological resources in the mixing and seawater zones. Anoxic events are reported in the seawater zone, and hypoxic events in the mixing and seawater zones. Extreme conditions are generally found in Jamaica Bay.

Most trends are stable or unknown except for an increase in chlorophyll *a* in Jamaica Bay. Decreasing trends occur in turbidity, nitrogen, phosphorus, and dissolved oxygen concentrations. SAV coverage varies from low to nonexistent, with stable or unknown trends.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **8,200** Avg. Daily Inflow *(cfs)* **26,700**

	Est.	TF	Mixing				Seawater	
			In Gen.	San. Hk.	Fresh K.	East R.	Lower Bay	Jamaica Bay
Surface Area *(mi²)*	304.5	41.9	111.6	14.9	0.4	12.7	101.7	7.8
Average Depth *(ft)*	20.8	17.4	24.3	15	13	42	21.7	16.1
Volume *(billion cu ft)*	180	18	75.8	6.2	0.1	14.9	61.5	3.5

Consists of a series of interconnected bays, rivers, and tidal straits. The two main bay systems are Raritan and Sandy Hook Bays. Responses of these areas to specific estuarine circulation forces are complex. Significant mixing occurs from East River south to the lower Bay area. Saltwater intrusion and freshwater discharge from the Hudson River greatly reduce residence time within the estuary. Tide range varies considerably throughout the system (~4.5 ft near the mouth of East River).

Algal Conditions

	Tidal Fresh		Mixing: In General		Mixing: Sandy Hook Bay		Seawater: Lower Bay		Seawater: Jamaica Bay	
Chlorophyll *a*	H	?	H 25-50%	---	M 0-10%	---	H 25-50%	---	H 25-50%	↑
Turbidity	M 25-50%	?	M 25-50%	---			M 50-100%	?	H 50-100%	↓
Nuisance Algae	N	?	Y	---			Y	---		
Toxic Algae	N	?	N	---			N	---		

Maximum chl-*a* conditions occur in summer in all zones, and early spring mixing and seawater. Light is limiting in all areas, except nitrogen in Lower Bay. Nuisance diatom blooms and highest turbidity occur early spring and summer.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	L	?	NS	---	VL	---

Pelagic community dominates primary productivity in mixing and seawater, but historically was pelagic and benthic. Pelagic community dominated by diatoms in tidal fresh, and diverse in mixing and seawater. Benthic community dominated by mullusks in tidal fresh, annelids in mixing, and annelids and crustaceans in seawater. SAV disappeared in 1930's due to wasting disease, and eutrophic conditions deter reestablishment.

Nutrients

	Tidal Fresh		Mixing: In General		Mixing: East River		Mixing: Fresh Kills		Seawater: Lower Bay		Seawater: Jamaica Bay	
Nitrogen	H ?	↓ ?	M 50-100%	---	H 50-100%	---	H 50-100%	---	M 50-100%	---	H 50-100%	---
Phosphorus	M ?	---	H 50-100%	↓	H 50-100%	↓	H 10-25%	↓	H 50-100%	↓	M 50-100%	↓

Elevated TDN concentrations occur March and July to September in mixing. Elevated TDP concentrations occur in mixing zone July to August; in seawater zone May and July to August. All nutrient trends associated with point sources.

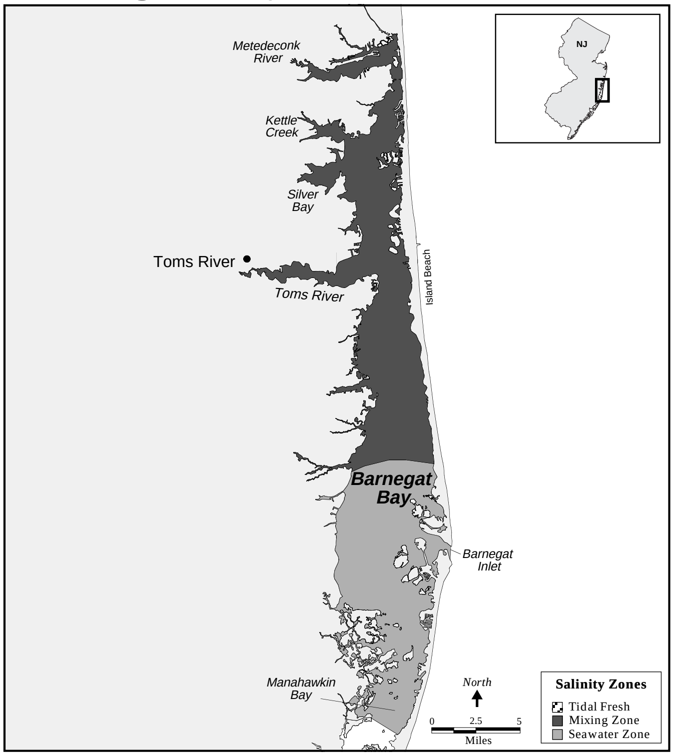
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	↓	Y 0-10%	?
Hypoxia	N	?	Y 0-10%	↓	Y 0-10%	?

Anoxic events occur June to August throughout water column in Jamaica Bay. Hypoxia occurs from June to August in bottom waters of seawater zone, and throughout water column in mixing zone. Water column stratification is highly significant factor. Decreases of event duration observed in mixing , and increases in seawater are associated with changes in point sources.

Key on page 21

Barnegat Bay



In Barnegat Bay, chlorophyll *a* and turbidity concentrations are high. Biological resources are impacted by nuisance algal blooms. Nitrogen concentrations were reported to be moderate and phosphorus low. No occurrences of anoxia / hypoxia were reported.

Chlorophyll *a* and nuisance and toxic algae have remained static since 1970 and trends for turbidity, nutrients and dissolved oxygen are unknown. SAV coverage is moderate with unknown trends.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **705** Avg. Daily Inflow *(cfs)* **1,340**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	71.0	0	33.7	37.3
Average Depth *(ft)*	4.6	0	5.3	4.0
Volume *(billion cu ft)*	9.1	0	5.0	4.2

A fairly narrow, bar-built estuary containing a series of interconnected embayments and inlets. Freshwater inflow is dominated by small coastal plain derived sources such as the Toms and Metedeconk rivers. Currents within the bay are driven mostly by wind events. Significant circulation occurs near dredged channels. Salinity structure tends to be vertically homogeneous throughout the estuary. Mean tidal range near Barnegat inlet is 3.1 ft and tides are dampened considerably within the main bay area.

Algal Conditions

	Tidal Fresh	Mixing		Seawater	
Chlorophyll *a*		H 50-100%	- - -	H 10-25%	- - -
Turbidity		H 50-100%	?	H 50-100%	?
Nuisance Algae		Y	- - -	Y	- - -
Toxic Algae		N	- - -	N	- - -

Chl-*a* maximums occur periodically during late winter and late summer, with nitrogen as the limiting factor. High turbidity events occur episodically during summer and are wind driven. nuisance *Nanochloris* spp. occurs periodically during summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		M	?	M	?

Primary productivity is a combination of pelagic and benthic communities. Planktonic and benthic communities are diverse.

Nutrients

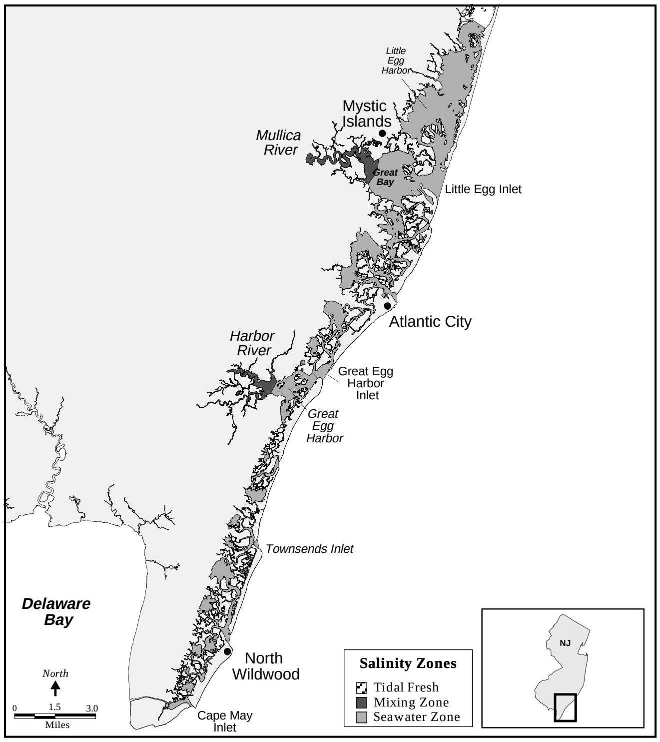
	Tidal Fresh	Mixing		Seawater	
Nitrogen		M 50-100%	?	M 25-50%	?
Phosphorus		L	?	L	?

Elevated concentrations of TDN occur December to February.

Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	N	?
Hypoxia		N	?	N	?

New Jersey Inland Bays



In New Jersey Inland Bays, chlorophyll *a* and turbidity concentrations are high. Nuisance algal blooms in the seawater zone are reported to impact biological resources. In both the mixing and seawater zones, nitrogen concentrations are moderate. There are no reported anoxic/hypoxic events. Most conditions are reported for both salinity zones.

Trends are reported as unknown or no trend, with the exception of increases in both chlorophyll *a* and nuisance algal blooms. SAV coverage is unknown in the mixing zone and high in the seawater zone with unknown trends.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,349** Avg. Daily Inflow *(cfs)* **2,360**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	**105.7**	**0**	**7.2**	**98.5**
Average Depth *(ft)*	**6.2**	**0**	**12.8**	**5.7**
Volume *(billion cu ft)*	**18.6**	**0**	**2.6**	**16**

A narrow, bar-built estuary containing a series of interconnected embayments, small sounds and inlets. Freshwater inflow is dominated by small coastal plain derived streams such as the Mullica and Harbor rivers. Significant circulation occurs near dredged channels. Salinity structure tends to be vertically homogeneous throughout the estuary. Tidal range is approximately 3.7 ft near the Little Egg Inlet and 4.1 ft near Wildwood, New Jersey.

Algal Conditions

	Tidal Fresh	Mixing		Seawater	
Chlorophyll *a*		H ?	↑	H ?	↑
Turbidity		H 50-100%	?	H 25-50%	?
Nuisance Algae		N	---	Y	↑
Toxic Algae		N	---	N	---

Chl-*a* maximums occur in late summer with nitrogen as the limiting factor. Trends are associated with changes in point/non-point sources and alterations to the basin. Highest turbidity occurs periodically during early summer. Nuisance *Nanochloris* blooms occur episodically during the summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		?	?	H	?

Primary productivity in the seawater zone is a mix of pelagic and benthic communities. Planktonic community in seawater is dominated by chlorophytes; benthic community is a diverse mixture.

Nutrients

	Tidal Fresh	Mixing		Seawater	
Nitrogen		M ?	?	M ?	?
Phosphorus		L	?	L	?

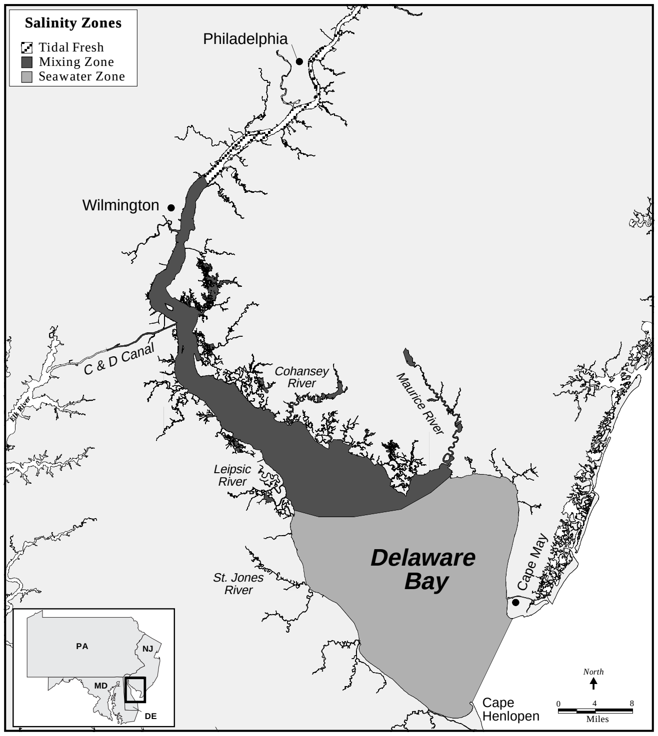
Elevated concentrations of TDN occur September to November.

Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	N	?
Hypoxia		N	?	N	?

Key on page 21

Delaware Bay



In Delaware Bay, chlorophyll *a* concentrations are high to hypereutrophic, and turbidity concentrations are moderate to high. Nuisance algal blooms in the tidal fresh zone are reported to have an impact on biological resources. In the tidal fresh zone, nitrogen and phosphorus concentrations are high, and elsewhere the maximums range from moderate to high. No occurrences of anoxia/hypoxia were observed.

Trends are reported to be stable for algal conditions, decreasing for nitrogen, increasing for phosphorus, and unknown for dissolved oxygen events. SAV is not present in any zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **6,751** Avg. Daily Inflow *(cfs)* **19,800**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	768.0	39.6	183.4	545.0
Average Depth *(ft)*	20.8	20.8	18.0	21.9
Volume *(billion cu ft)*	445	23	92	330

A large riverine system with circulation dominated by discharge from the Delaware River. Salinity is highly variable due to flow changes from the Delaware River and freshwater runoff from coastal plain derived sources. Salinity stratification is more pronounced in the spring months. Wind is also important in the longterm transport of materials within the bay. Tides range approximately 1 ft near the mouth of the bay to approximately 6 ft near the Cohansey River.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*	H ?	---	H ?	---	E ?	---
Turbidity	H ?	---	H ?	---	M ?	---
Nuisance Algae	Y	---	N	---	N	---
Toxic Algae	N	---	N	---	N	---

Maximum chl-*a* concentrations occur periodically in summer with light limiting in tidal fresh and mixing zones, and nitrogen in seawater zone. Turbidity conditions occur all year.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	H ?	↓	H ?	↓	M ?	↓
Phosphorus	H ?	↑	M ?	↑	M ?	↑

Elevated concentrations of TDN occur December to February, and of TDP occur October to December. TDP trends are associated with point sources.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	NS	---	NS	---	NS	---

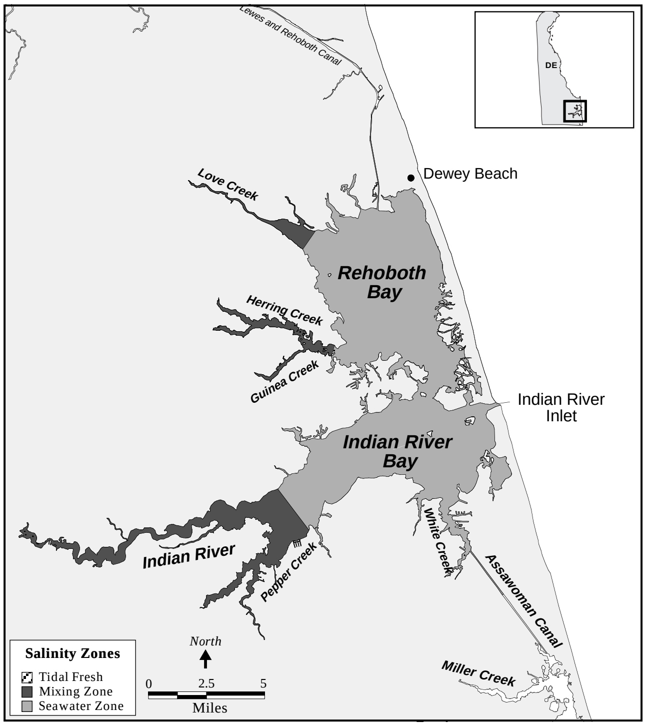
Primary productivity dominated by pelagic community. Tidal fresh planktonic community is diverse mixture; mixing and seawater dominated by diatoms. Benthic community is diverse mixture in tidal fresh and mixing, and combination of annelids and crustaceans in seawater. Dermo contributed to loss of benthic diversity in seawater.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	?	N	?	N	?
Hypoxia	N	?	N	?	N	?

The duration and spatial coverage of anoxic events were reported to decrease in the mixing zone, and decrease in both tidal fresh and mixing for hypoxic events. Decreases are associated with point sources.

Delaware Inland Bays



In Delaware Inland Bays, chlorophyll *a* and turbidity concentrations are high. Nuisance algal blooms are reported to have an impact on biological resources in the tidal fresh zone. Concentrations of nitrogen and phosphorus are reported as high. No anoxic/hypoxic events were observed.

For most parameters, conditions remained static since 1970. However, trends are unknown for toxic algae and for dissolved oxygen events. SAV is not present in either zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **248** Avg. Daily Inflow *(cfs)* **340**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	**32.0**	**0**	**6.0**	**26.0**
Average Depth *(ft)*	**4.2**	**0**	**4.0**	**4.2**
Volume *(billion cu ft)*	**3.7**	**0**	**0.7**	**3.0**

A shallow system consisting of Rehoboth and Indian River bays. Considered a partially mixed estuary but salinity stratification occurs, especially during spring months. Circulation dominated by tidal influences. Water column mixing occurs because of the high tidal influence, shallow depths, and wind. There are no major freshwater sources to the bays. Tidal range is approximately 3 ft near Indian River Inlet.

Algal Conditions

	Tidal Fresh	Mixing		Seawater	
Chlorophyll *a*		H ?	---	H ?	---
Turbidity		H ?	---	H ?	---
Nuisance Algae		Y	---	Y	---
Toxic Algae		N	?	N	?

Chl-*a* maximums occur periodically in summer with phosphorus as limiting factor in mixing zone, co-limiting with nitrogen in seawater zone. Maximum turbidity occurs in January and in summer. Nuisance green algae also occurs with high turbidity in summer.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater	
SAV		NS	---	NS	---

Primary productivity dominated by pelagic community. Mixing zone planktonic community is diverse mixture and seawater is dominated by diatoms. Benthic community is dominated by annelids in mixing and crustaceans in seawater .

Nutrients

	Tidal Fresh	Mixing		Seawater	
Nitrogen		H ?	---	H ?	---
Phosphorus		H ?	---	H ?	---

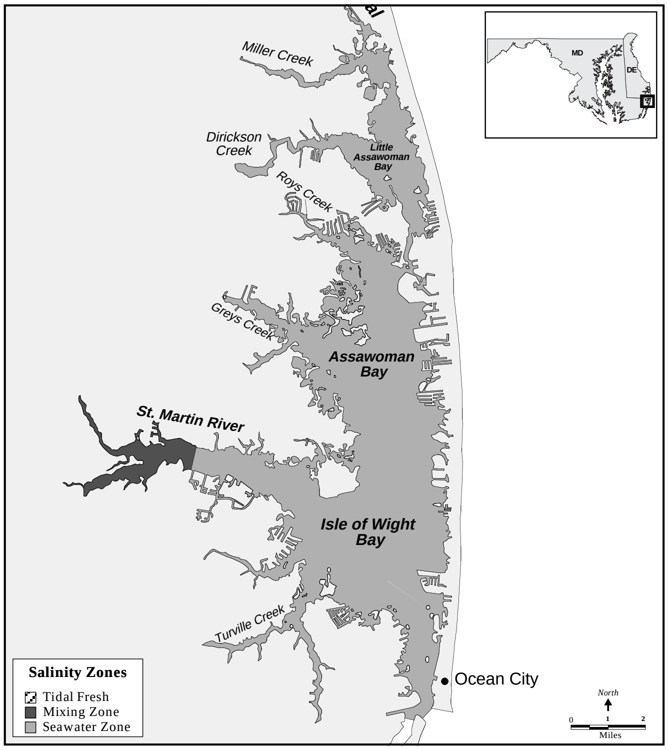
Elevated concentrations of TDN occur March to May in mixing zone. Elevated concentrations of TDP occur between July and August.

Dissolved Oxygen

	Tidal Fresh	Mixing		Seawater	
Anoxia		N	?	N	?
Hypoxia		N	?	N	?

Key on page 21

Maryland Inland Bays



In Maryland Inland Bays, chlorophyll *a* concentrations range from high to hypereutrophic, and turbidity is high. Biological resource impacts due to toxic algal blooms are reported in the seawater zone. Nitrogen concentrations are reported as medium to high, and phosphorus concentrations are high. There are no observations of anoxic / hypoxic events.

Chlorophyll *a*, nitrogen, and phosphorus decreased in the mixing zone, and were no trend or unknown elsewhere. SAV is not present in the mixing zone, and is low in the seawater zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area (mi^2) **260** Avg. Daily Inflow (*cfs*) **n/a**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area (mi^2)	**21.0**	**0**	**0.9**	**20.1**
Average Depth (*ft*)	**5.4**	**0**	**3.8**	**5.5**
Volume (*billion cu ft*)	**3.2**	**0**	**0.1**	**3.1**

A shallow system consisting of Isle of Wight, Assawoman, and Little Assawoman bays. Circulation is dominated by tidal influences. Considered a partially mixed estuary, but salinity stratification occurs especially during spring months. Water column mixing occurs due to tidal influences, shallow depths, and wind. The St. Martin River is the only significant freshwater inflow into the bays. Tidal range is approximately 3 ft near Ocean City, Maryland.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll a			E (50-100%)	↓	H (50-100%)	---
Turbidity			H (?)	---	H (?)	?
Nuisance Algae			N	---	N	---
Toxic Algae			N	?	Y	?

Maximum chl-*a* occurs periodically in summer with phosphorus, nitrogen and light limiting in mixing, and nitrogen and phosphorus limiting in seawater. High turbidity occurs periodically summer and episodically rest of year. Toxic *H*ematodinium perezi bloom occurred summer 1992.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen			H (50-100%)	↓	M (50-100%)	?
Phosphorus			H (?)	↓	H (50-100%)	---

Elevated nutrient concentrations occur between June and August. Trends are associated with point sources.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV			NS	---	L	?

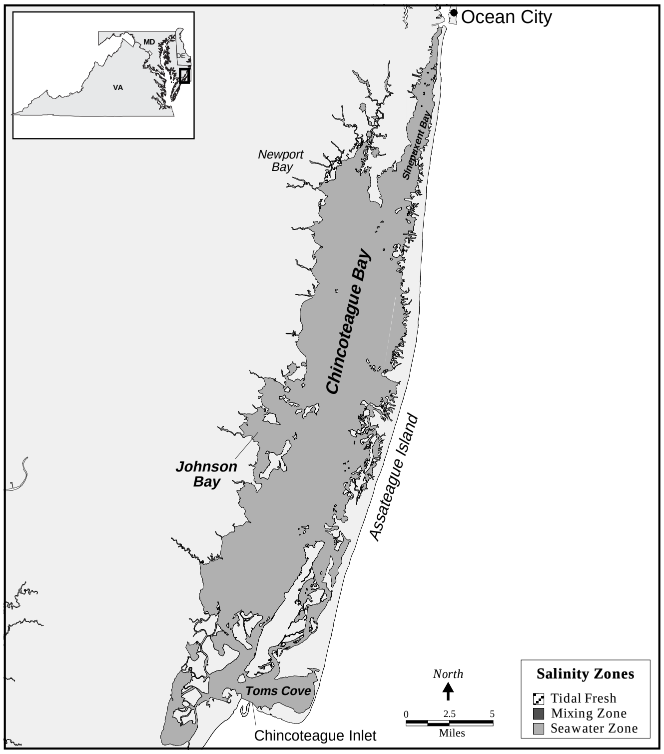
Primary productivity in mixing zone dominated by pelagic community. Planktonic community dominated by flagellates; benthic community dominated by mollusks in mixing and crustaceans in seawater.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia			N	?	N	?
Hypoxia			N	?	N	?

Key on page 21

Chincoteague Bay



In Chincoteague Bay, chlorophyll *a* , nitrogen, and phosphorus concentrations are moderate, and turbidity is high. There are no known biological resource impacts due to nuisance or toxic algal blooms. There are also no observations of anoxic/hypoxic events.

Most of the trends are unknown, except for no trend in turbidity and decreases for nitrogen and phosphorus since 1970. SAV coverage is low and has increased slightly.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **320** Avg. Daily Inflow *(cfs)* **400**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	**137.0**	**0**	**0**	**137.0**
Average Depth *(ft)*	**5.9**	**0**	**0**	**5.9**
Volume *(billion cu ft)*	**23**	**0**	**0**	**23**

A fairly shallow, bar-built estuary containing a series of interconnected embayments, small sounds and inlets. Freshwater inflow is dominated by small coastal plain derived streams. Salinity structure is vertically homogeneous throughout the estuary. Tidal range is approximately 3.6 ft near Chincoteague inlet and is dampened considerably within Chincoteague Bay.

Algal Conditions

	Tidal Fresh	Mixing	Seawater
Chlorophyll *a*			M 50-100% ?
Turbidity			H 50-100% ---
Nuisance Algae			N ?
Toxic Algae			? ?

Maximum chl-*a* and turbidity occur periodically in summer, with a limiting factor of nitrogen for chl-*a*..

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV			L ⇧

Benthic community is dominated by annelids.

Nutrients

	Tidal Fresh	Mixing	Seawater
Nitrogen			M 50-100% ⇩
Phosphorus			M 50-100% ⇩

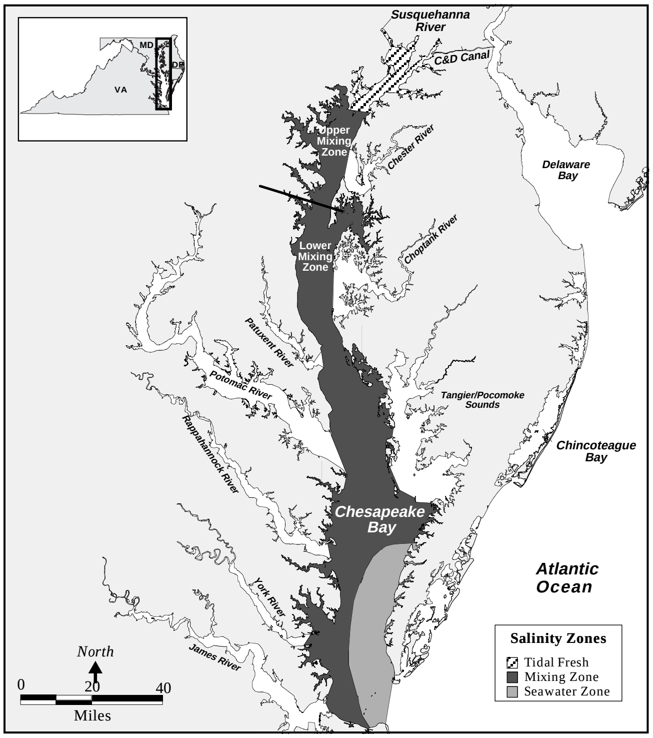
Elevated concentrations of nutrients occur in summer. Trends are associated with point sources.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia			N ?
Hypoxia			N ?

Key on page 21

Chesapeake Bay (Mainstem)



In the Chesapeake Bay, chlorophyll *a* concentrations range from moderate to hypereutrophic and turbidity ranges from low to high. There are no biological resource impacts from toxic or nuisance algal blooms. Nitrogen and phosphorus concentrations range from medium to high. Anoxia and hypoxia events occur in the mixing zone.

High magnitude increases of chlorophyll *a* occurred from 1950-1979 and leveled off since. Turbidity and nuisance/toxic algae have remained static since 1970. In the mixing zone, it is speculated that nitrogen increased and phosphorus decreased since 1984. The spatial extent of anoxia and hypoxia increased slightly from 1950 to 1984. SAV coverage ranges from low to medium and since 1980 has increased in the mixing and seawater zones.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **24,730** Avg. Daily Inflow *(cfs)* **85,800**

	Estuary	Tidal Fresh	Mixing: Upper Zone	Mixing: Lower Zone	Seawater
Surface Area *(mi²)*	**2,659.8**	**92.8**	**275.0**	**1849.0**	**446.5**
Average Depth *(ft)*	**30.7**	**12.9**	**20.9**	**35.4**	**30.2**
Volume *(billion cu ft)*	**2276.6**	**33**	**160.2**	**1051**	**1032**

A large drowned river valley system containing a long, extensive shoreline. The main stem consists of fairly deep channels (60+ ft) and higher mean salinities derived from ocean waters. The Susquehanna is the main freshwater source into the upper bay. A two-layer density structure is apparent during all seasons of the year. Salinity variability is more apparent near the head of the bay. Tides range near 3.0 ft near the mouth and decrease to less than 1 ft toward the head of the bay. Wind influences from storm events also greatly affect circulation within the bay as well.

Algal Conditions

	Tidal Fresh		Mixing				Seawater	
Chlorophyll *a*	H (50-100%)	?	E (50-100%)	---			M (?)	---
Turbidity	H (50-100%)	---	Lower Zone: M (50-100%)	---	Upper Zone: H (10-25%)	---	L	---
Nuisance Algae	N	---	N	---			N	---
Toxic Algae	N	---	N	---			N	---

In tidal fresh zone, maximum chl-*a* occurs periodically during winter and summer with phosphorus and light as limiting factors; the mixing and seawater zones have periodic occurrences in spring with nitrogen as limiting factor. The mixing zone also has episodic high chl-*a* events in summer. Maximum turbidity occurs during spring in tidal fresh and upper mixing zones, and throughout year in lower mixing zone. Chl *a* concentrations were reported to have increased from 1950-1979 then leveled off in the mixing zone.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	L	---	L	↑	M	↑

Primary productivity pelagically dominated. Planktonic community dominated by diatoms in spring, and flagellates in summer. Benthic community dominated by annelids.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	H (50-100%)	---	H (10-25%)	↑*	M (50-100%)	---
Phosphorus	M (25-50%)	---	H (25-50%)	↓*	M (50-100%)	---

In tidal fresh zone, elevated concentrations of nutrients occur all year. In mixing and seawater zones, elevated concentrations of TDN occur in spring, and TDP in summer. TDN trends in mixing zone associated with point and non-point sources, and TDP trends in mixing zone associated with point sources. In the tidal fresh zone, nitrogen concentrations were reported to have increased slightly from 1978-1984 then leveled off.

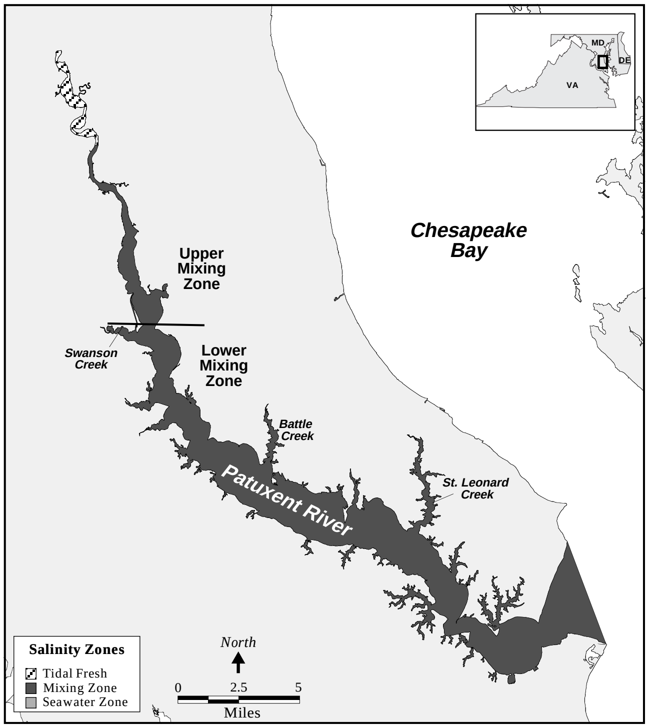
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	---	Y (25-50%)	---	N	?
Hypoxia	N	---	Y (25-50%)	---	N	?

Low dissolved oxygen conditions occur periodically in bottom-waters during summer. Water column stratification is highly significant factor. Spatial extent of anoxia and hypoxia has increased from 1950-1984 in the mixing zone due to point and non-point sources.

Key on page 21

Patuxent River



In the Patuxent River, chlorophyll *a* concentrations range from high to hypereutrophic, and turbidity is high. Nuisance algal blooms have an impact on biological resources in the mixing zone. Nitrogen concentrations are high, and phosphorus ranges from medium to high. Anoxia and hypoxia are reported to occur in the lower mixing zone.

Increases of chlorophyll *a* occurred in the tidal fresh zone from 1984-1994 and increases of chlorophyll *a* , turbidity and nuisance algae events occurred in the mixing zone from 1960 to 1984 and then leveled off. Nutrient concentrations have decreased since 1980. The spatial coverage and duration of low dissolved oxygen events increased from 1930 to 1979 and then leveled off. SAV coverage is low with a medium increase in the tidal fresh zone since 1984.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **932** Avg. Daily Inflow *(cfs)* **938**

	Estuary	Tidal Fresh	Mixing: Upper Zone	Mixing: Lower Zone	Seawater
Surface Area *(mi²)*	50.6	1.4	4.2	45.0	0
Average Depth *(ft)*	19.3	4.2	10.1	20.4	0
Volume *(billion cu ft)*	27	0.18	1.2	25.6	0

A drowned river valley system to the mainstem of the Chesapeake Bay. Waters are moderately stratified especially during spring flow conditions. Influence from the main bay is apparent in circulation and density distributions within the river. Tides are approximately 1 ft. near the mouth.

Algal Conditions

	Tidal Fresh		Mixing: Upper Zone		Mixing: Lower Zone		Seawater
Chlorophyll *a*	H (50-100%)	↑	E (10-25%)	---	E (10-25%)	---	
Turbidity	H (50-100%)	---	H (50-100%)	---	H (25-50%)	---	
Nuisance Algae	N	---	Y	---			
Toxic Algae	N	---	N	---			

Tidal fresh chl-*a* maximums occur in summer with light and nitrogen limiting. Mixing zone chl-*a* maximums occur June through March, with nitrogen and phosphorus limiting. Turbidity occurs persistently. Nuisance *Gymnodium*, *Katodinium*, and *Prorocentrum* occur periodically in January and summer for weeks at a time. In the mixing zone, chl *a* concentrations and turbidity have increased from 1960-1984 then leveled off.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater
SAV	L	---	L	---	

Tidal fresh planktonic community dominated by blue-green algae in summer/fall; mixing zone by flagellates and diatoms in summer/fall, and diatoms in spring. Benthic community dominated by annelids in tidal fresh, and by annelids, crustaceans, and mollusks in mixing. In tidal fresh zone, increases in SAV were reported from 1984-1991.

Nutrients

	Tidal Fresh		Mixing: Upper Zone		Mixing: Lower Zone		Seawater
Nitrogen	H (50-100%)	⇩	H (50-100%)	⇩	H (50-100%)	---	
Phosphorus	H (10-25%)	↓	M (50-100%)	↓	M (25-50%)	⇩	

Elevated nutrient concentrations occur throughout the year. Trends are associated with point sources

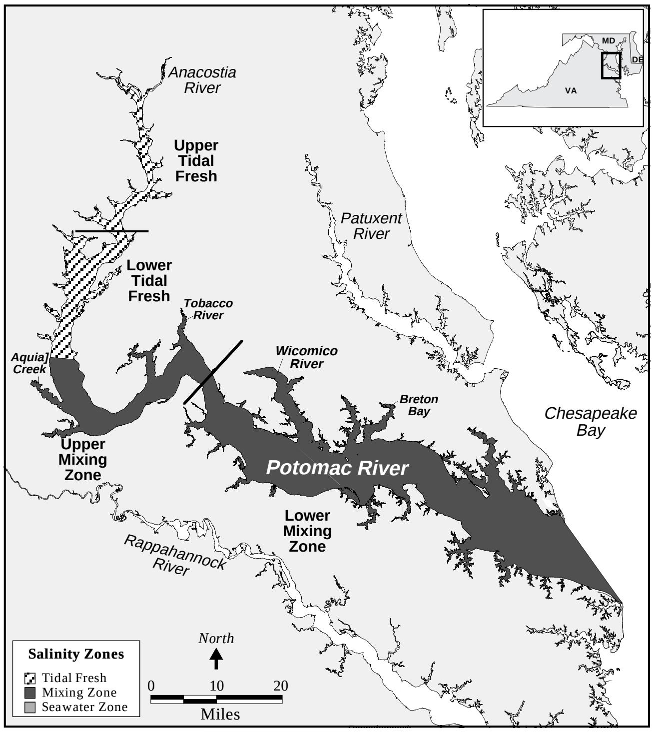
Dissolved Oxygen

	Tidal Fresh		Mixing: Upper Zone		Mixing: Lower Zone		Seawater
Anoxia	N	---	N	---	Y (10-25%)	---	
Hypoxia	N	---	N	---	Y (25-50%)	---	

Periodic occurrences of anoxia and hypoxia occur in bottom-waters during summer. Water column stratification is a highly significant factor. The duration and spatial coverage of anoxic/hypoxic events were reported to have increased during 1930-1979.

Key on page 21

Potomac River



In the Potomac River, chlorophyll *a* concentrations range from high to hypereutrophic, and turbidity is high. In the lower tidal fresh zone and the mixing zone, nuisance algal blooms are reported to have an impact on biological resources. Nitrogen concentrations are high, and phosphorus concentrations are medium. Anoxic and hypoxic events occur in the mixing zone.

Chlorophyll *a*, turbidity, nuisance algae, and phosphorus all decreased since 1970. Nitrogen concentrations increased from 1970 to 1989 and then leveled off. A slight increase in the spatial coverage of hypoxia occurred from 1970 to 1994. SAV coverage ranges from non-existent in the lower mixing zone to medium in the tidal fresh zone. High magnitude decreases of SAV occurred from 1950 to 1984 and then high magnitude increases occurred from 1985 to 1994.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **3,139** Avg. Daily Inflow *(cfs)* **15,900**

	Estuary	Tidal Fresh		Mixing		Seawater
		Upper Zone	Lower Zone	Upper Zone	Lower Zone	
Surface Area *(mi²)*	**494.0**	**24.0**	**51.0**	**70.6**	**337.0**	**0**
Average Depth *(ft)*	**19.3**	**11.5**	**13.8**	**13.6**	**22.5**	**0**
Volume *(billion cu ft)*	**265**	**7.7**	**19.6**	**26.8**	**211**	**0**

A drowned river valley system to the mainstem of the Chesapeake Bay. This extensive estuary has fairly high discharge rates and a significant portion of tidal fresh zone (75 mi²). The upper and lower mixing zones exhibit vertical stratification of salinities and a two-layer flow characteristic. Tidal range is approximately 1.3 ft near the mouth and 1.6 ft upstream near the confluence of the Wicomico River.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
	Upper Zone	Lower Zone	Upper Zone	Lower Zone	
Chlorophyll *a*	E (50-100%) ---		E (10-25%) ⇩	H (50-100%) ⇩	
Turbidity	H (50-100%) ---		H (?) ⇩ ?	H (?) ⇩ ?	
Nuisance Algae	N ---	Y ⇩ ?	Y ⇩ ?		
Toxic Algae	? ?	N ---	N ---		

Tidal fresh and upper mixing chl-*a* maximums occur summer. Light, phosphorus and flow limit in tidal fresh and phosphorus in mixing. Lower mixing chl-*a* maximums occur spring with nitrogen limiting. Turbidity occurs all year. Tidal fresh nuisance *Microcystis* blooms occur in summer for days, and *Prorocentrum* blooms occur episodically in mixing zone.

Nutrients

	Tidal Fresh	Mixing		Seawater
		Upper Zone	Lower Zone	
Nitrogen	H (50-100%) ---	H (50-100%) ---	H (25-50%) ---	
Phosphorus	M (50-100%) ⬇	M (?) ⇩	M (?) ⇩	

Elevated concentrations of TDN occur all year in tidal fresh; December to June in mixing. TDP concentrations occur all year. In the mixing zone, phosphorus concentrations were reported to have decreased from 1970-1989.

Ecosystem/Community Responses

	Tidal Fresh	Mixing		Seawater
		Upper Zone	Lower Zone	
SAV	M ⬆	L ⬆	NS ---	

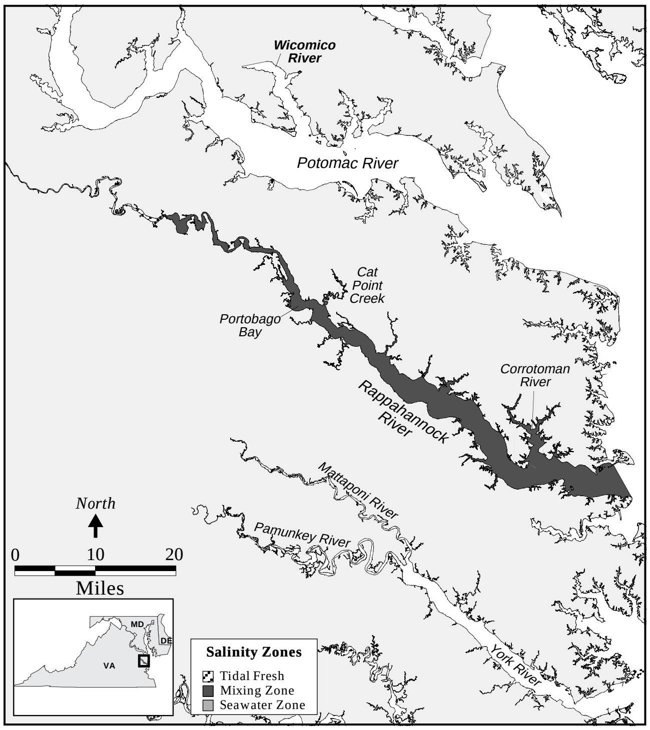
Tidal fresh plankton dominated spring/fall by flagellates/diatoms, and in summer by blue-green algae. Mixing zone dominated by diatoms in spring, flagellates and blue-green algae in summer, flagellates and diatoms in fall. Benthic community dominated by annelids. SAV coverage was reported to have decreased from 1950-1984; increased from 85-94.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia	N ---	Y (10-25%) ---	
Hypoxia	N ---	Y (10-25%) ---	

Anoxia/hypoxia occur in bottom waters May to September. Water column stratification is highly significant influence. Changes in point sources and freshwater inflow have caused increases in spatial coverage of hypoxia.

Rappahannock River



In the Rappahannock River, chlorophyll *a* and turbidity concentrations are high. There are no reported biological resource impacts due to nuisance or toxic algal blooms. Nitrogen concentrations are medium to high, and phosphorus concentrations are medium. Anoxic and hypoxic events occur in the mixing zone.

Most trends have been stable from 1985 to 1994, except for an increase in chlorophyll *a* and phosphorus. Dissolved oxygen trends are unknown. SAV coverage is very low to low and has increased moderately in the mixing zone.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,169** Avg. Daily Inflow *(cfs)* **2,900**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	**145.0**	**3.0**	**142.0**	**0**
Average Depth *(ft)*	**16.2**	**12.3**	**16.3**	**0**
Volume *(billion cu ft)*	**66**	**1.0**	**65**	**0**

A drowned river valley system to the mainstem of the Chesapeake Bay. This long estuary has fairly low freshwater discharge rates and generally a small portion of tidal fresh zone. The middle and lower areas of the river exhibit vertical stratification of salinities and a two-layer flow characteristic. Tidal range is approximately 1.2 ft near the mouth.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
Chlorophyll *a*	H 25-50%	↑	H 10-25%	↑	
Turbidity	H 50-100%	---	H ?	---	
Nuisance Algae	N	---	N	---	
Toxic Algae	N	---	N	---	

High chl-*a* occurs late spring and summer with phosphorus limiting in tidal fresh, co-limiting with light in mixing. High turbidity occurs spring tidal fresh, and summer mixing.

Nutrients

	Tidal Fresh		Mixing		Seawater
Nitrogen	H 25-50%	---	M 50-100%	---	
Phosphorus	M 50-100%	↑	M 50-100%	---	

Elevated concentrations of TDN occur in spring, and TDP occur in summer. TDP trend is associated with changes in non-point sources.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater
SAV	VL	---	L	↑	

Tidal fresh planktonic community dominated in winter by flagellates, in spring by diatoms, and in fall by diatoms and flagellates. Mixing zone planktonic community dominated in spring by diatoms, and in summer by flagellates. Benthic community dominated by annelids.

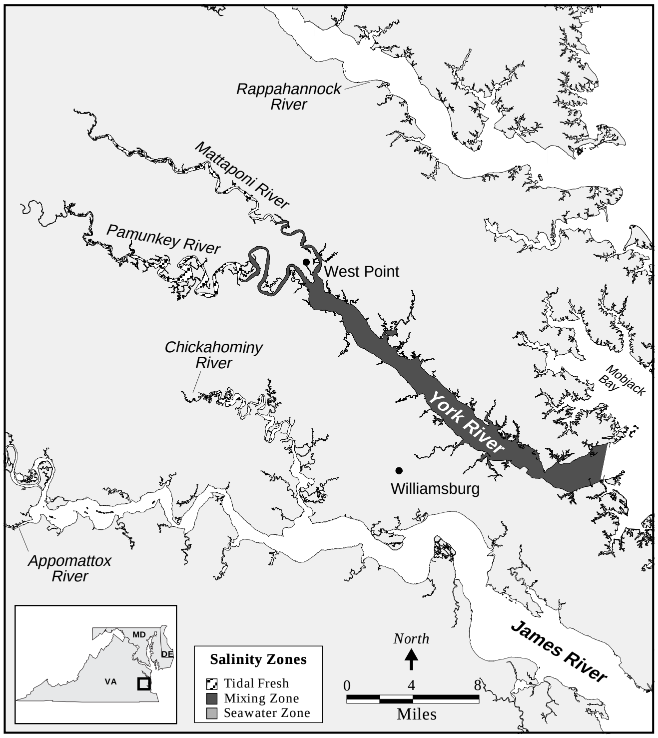
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater
Anoxia	N	?	Y 10-25%	?	
Hypoxia	N	?	Y 10-25%	?	

Periodic occurrences of anoxia/hypoxia occur in bottom-waters during summer. Water column stratification significant factor in the expression of low dissolved oxygen in bottom waters.

Key on page 21

York River



In the York River, chlorophyll *a* concentrations are moderate, and turbidity is high. There are no biological resource impacts from nuisance or toxic algal blooms. Nitrogen and phosphorus concentrations are moderate. Occurrences of anoxia and hypoxia are reported in the mixing zone.

Most trends remained static from 1985 to 1994 except increases in chlorophyll *a* and phosphorus concentrations. SAV coverage is low, and has not changed.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **2,654** Avg. Daily Inflow *(cfs)* **2,500**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	**74.0**	**7.0**	**67.0**	**0**
Average Depth *(ft)*	**15.6**	**12.2**	**16.0**	**0**
Volume *(billion cu ft)*	**32**	**2.4**	**30**	**0**

A drowned river valley system to the mainstem of the Chesapeake Bay. Formed at the confluence of the Mattaponi and Pamunkey Rivers. Stratification occurs as a result of significant density gradients due to the influences of the two river systems. Tides range approximately 2.2 ft near the mouth and range continues to increase in the tributaries reaching 3.9 ft in the Mattaponi.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
Chlorophyll *a*	M (?)	↑	M (?)	↑	
Turbidity	H (?)	- - -	H (50-100%)	- - -	
Nuisance Algae	N	- - -	N	- - -	
Toxic Algae	N	- - -	N	- - -	

Maximum chl-*a* occurs periodically in summer in the tidal fresh zone and in spring in the mixing zone. Phosphorus and light are the limiting factors in the tidal fresh zone, and phosphorus in the mixing zone. Turbidity maximums occur in the spring.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater
SAV	L	- - -	L	- - -	

Planktonic community is dominated by diatoms; benthic community is dominated by annelids in the tidal fresh zone and mollusks in the mixing zone.

Nutrients

	Tidal Fresh		Mixing		Seawater
Nitrogen	M (50-100%)	- - -	M (50-100%)	- - -	
Phosphorus	M (50-100%)	↑	M (50-100%)	- - -	

Elevated concentrations of TDN occur December to April in tidal fresh zone, and July to November in the mixing zone. Elevated concentrations of TDP occur in summer with trends related to changes in non-point sources.

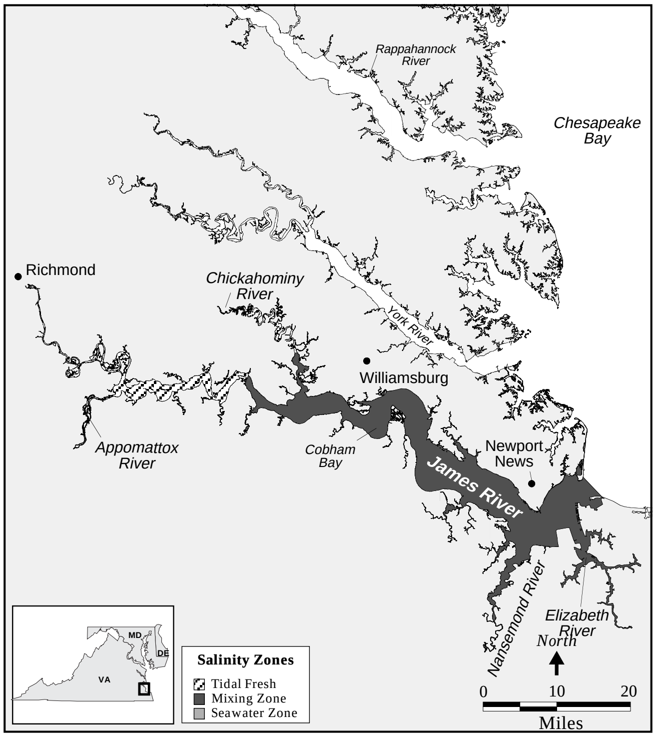
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater
Anoxia	N	?	Y (10-25%)	?	
Hypoxia	N	?	Y (10-25%)	?	

Bottom-water anoxia/hypoxia occur periodically from June to September. Water column stratification is a highly significant factor.

Key on page 21

James River



In the James River, chlorophyll *a* concentrations range from high to hypereutrophic, and turbidity is high. There are no reported biological resource impacts due to nuisance or toxic algal blooms. In the tidal fresh zone, nitrogen and phosphorus concentrations are high, and in the mixing zone concentrations are moderate. There are no reported anoxic or hypoxic events.

Most trends are stable except an increase in chlorophyll *a*. SAV does not exist in the tidal fresh zone, and is low in the mixing zone with an increasing trend.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **4,447** Avg. Daily Inflow *(cfs)* **12,500**

	Estuary	Tidal Fresh: In General	Tidal Fresh: Subarea(s)	Mixing	Seawater
Surface Area *(mi2)*	236.0	22.0	10	204.0	0
Average Depth *(ft)*	13.7	11.1	11.4	14.1	0
Volume *(billion cu ft)*	90	6.8	3.2	80	0

A drowned river valley system to the mainstem of the Chesapeake Bay. This long estuary has fairly high freshwater discharge rates and a significant portion of tidal fresh zone (32 mi^2). The middle and lower reaches exhibit vertical stratification of salinities and a two-layer flow characteristic. Tidal range is approximately 2.5 ft near the mouth and approximately 2 ft upstream near Cobham Bay.

Algal Conditions

	Tidal Fresh: In General	Tidal Fresh: Subareas	Mixing	Seawater
Chlorophyll *a*	H 50-100% ↑	E 10-25% ↑	H 10-25% ↑	
Turbidity	H 50-100% ---		H 50-100% ---	
Nuisance Algae	N ---		N ---	
Toxic Algae	N ---		N ---	

In tidal fresh, chl-*a* maximums occur periodically in summer with light limiting; in mixing maximums occur periodically in spring with phosphorus limiting. Turbidity maximums occur throughout year.

Ecosystem/Community Responses

	Tidal Fresh	Mixing	Seawater
SAV	NS ---	L ↑	

Planktonic community is dominated by diatoms; benthic community is dominated by annelids.

Nutrients

	Tidal Fresh	Mixing	Seawater
Nitrogen	H 50-100% ---	M 50-100% ---	
Phosphorus	H 50-100% ---	M 50-100% ---	

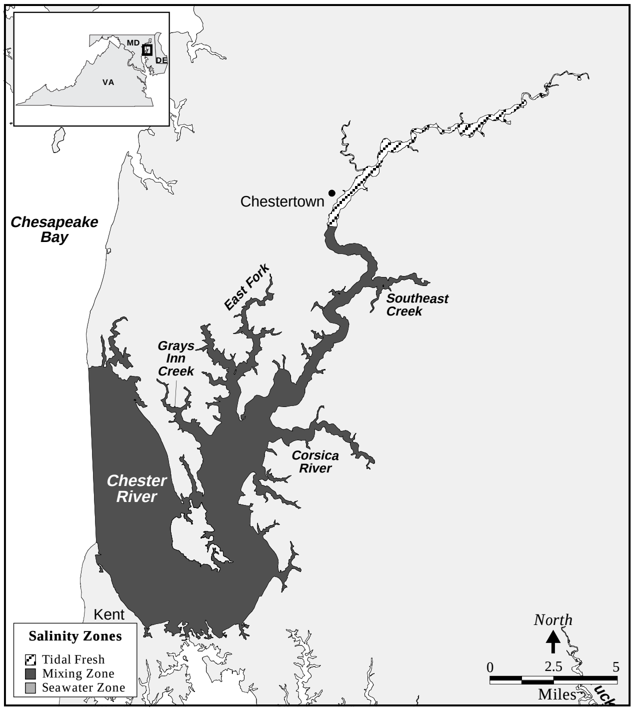
Elevated concentrations of TDN occur March to October in tidal fresh, and all year long in mixing zone. Elevated concentrations of TDP occur between June and October in tidal fresh, and throughout year in mixing zone.

Dissolved Oxygen

	Tidal Fresh	Mixing	Seawater
Anoxia	N ?	N ?	
Hypoxia	N ?	N ?	

Key on page 21

Chester River



In the Chester River, maximum chlorophyll *a* concentrations range from high to hypereutrophic, and maximum turbidities are moderate to high. Biological resource impacts due to nuisance or toxic algal blooms are either unknown or not observed. Maximum nitrogen concentrations are recorded as medium or high, and maximum phosphorus concentrations are medium. Anoxic and hypoxic events occur in the mixing zone.

Trends are recorded as stable or unknown. There is no SAV coverage in the tidal fresh zone, and it is low in the mixing zone with an increasing trend.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi²)* **520** Avg. Daily Inflow *(cfs)* **521**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi²)*	**57.4**	**5.2**	**52.2**	**0**
Average Depth *(ft)*	**13.8**	**6.7**	**14.6**	**0**
Volume *(billion cu ft)*	**22**	**1.0**	**21**	**0**

A fairly shallow tributary to the Chesapeake Bay. Minimal freshwater is supplied from mainland freshwater runoff, and lateral flow from nearby tidal creeks. A two-layer flow pattern is dominant within the mid-estuary. Salinity stratification occurs throughout the river. Winds are a significant forcing mechanism on the circulation in most of the estuary. Tidal range is approximately 1.1 ft near the mouth.

Algal Conditions

	Tidal Fresh		Mixing		Seawater	
Chlorophyll *a*	E 50-100%	---	H 50-100%	---		
Turbidity	H 50-100%	---	M 50-100%	---		
Nuisance Algae	?	?	N	?		
Toxic Algae	?	?	N	?		

Maximum chl-*a* concentrations occur spring to fall with phosphorus and light limiting in tidal fresh, and phosphorus and nitrogen in mixing. Maximum turbidity occurs all year.

Nutrients

	Tidal Fresh		Mixing		Seawater	
Nitrogen	H 50-100%	---	H 25-50%	---		
Phosphorus	M 50-100%	---	M 50-100%	---		

Elevated concentrations of TDN occur November to June. Elevated concentrations of TDP occur throughout the year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater	
SAV	NS	---	L	⇧		

Mixing zone planktonic community dominated year-round by flagellates, and in spring by diatoms. Benthic dominated by annelids.

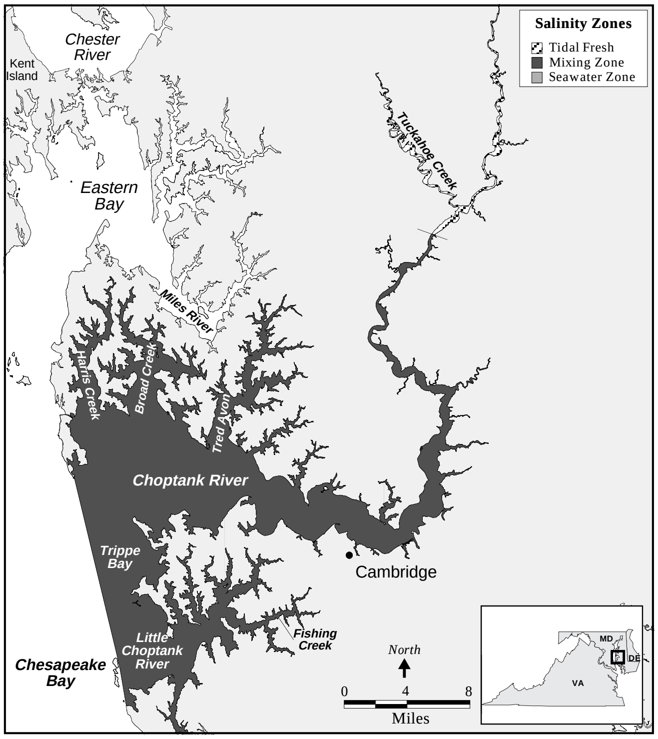
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater	
Anoxia	N	---	Y 10-25%	---		
Hypoxia	N	---	Y 10-25%	---		

Episodic occurrences of anoxia, and periodic occurrences of hypoxia occur in bottom waters June to August. Water column stratification is moderate factor in development of low dissolved oxygen conditions.

Key on page 21

Choptank River



In the Choptank River, maximum chlorophyll *a* concentrations are high, and maximum turbidity is moderate to high. In the mixing zone, biological resources are reported to be impacted by nuisance algal blooms. Maximum nitrogen concentrations range from medium to high, and maximum phosphorus concentrations are medium. Anoxic and hypoxic events occur in the mixing zone.

Most trends are reported as stable except a decrease in turbidity and phosphorus, and an increase in anoxia and hypoxia. There is no SAV coverage in the tidal fresh zone, and it is low in the mixing zone with an increasing trend.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi2)* **1,339** Avg. Daily Inflow *(cfs)* **1.028**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi2)*	110.2	3.0	107.2	0
Average Depth *(ft)*	13.1	10.6	13.2	0
Volume *(billion cu ft)*	40	0.89	39	0

A tributary to the Chesapeake Bay consisting of the Choptank River and several tidal creeks and bays. The area receives minimal freshwater supply from mainland freshwater runoff, and lateral flow from nearby tidal creeks. A two-layer flow pattern is dominant within the mid-estuary. Salinity stratification occurs throughout the river. Winds are a significant forcing mechanism on the circulation in most of the estuary. Tidal range is approximately 1.1 ft near the mouth.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
Chlorophyll *a*	H 50-100%	---	H 10-25%	---	
Turbidity	H 50-100%	---	M 50-100%	↓	
Nuisance Algae	N	---	Y	---	
Toxic Algae	N	---	N	---	

Chl-*a* maximums occur periodically in summer and fall with light and nitrogen limiting. Turbidity maximums occur continuously throughout the year. Nuisance *Katodinium* and dinoflagellate blooms occur periodically in summer with durations of days to weeks.

Nutrients

	Tidal Fresh		Mixing		Seawater
Nitrogen	H 50-100%	---	M 50-100%	---	
Phosphorus	M 50-100%	---	M 50-100%	↓ ?	

Elevated concentrations of TDN occur February to May. In tidal fresh, elevated concentrations of TDP occur throughout year, and in mixing zone in summer.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater
SAV	NS	---	L	↑	

Planktonic community dominated by diatoms, except in mixing zone where flagellates dominate in summer. Benthic community dominated by annelids. In the mixing zone, decreases were reported in SAV from 1950-1979. Increases in coverage from 1980-94 are associated with changes in non-point sources.

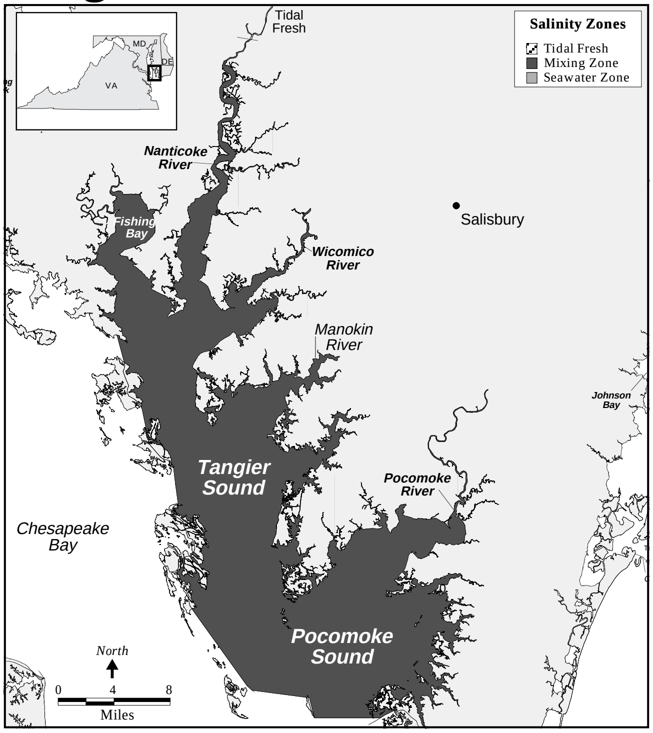
Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater
Anoxia	N	---	Y 10-25%	↑	
Hypoxia	N	---	Y 10-25%	↑	

Episodic bottom water anoxia/hypoxia events occur from June to September. Water column stratification has slight influence on low dissolved oxygen conditions.

Key on page 21

Tangier/Pocomoke Sounds



In Tangier / Pocomoke Sounds, maximum chlorophyll *a* concentrations are moderate to high, and maximum turbidity is high. Biological resource impacts due to nuisance or toxic algal blooms are either unknown or not observed. Maximum nitrogen and phosphorus concentrations are reported as high in the tidal fresh zone and medium in the mixing zone. There are no occurrences of anoxia or hypoxia.

Trends are increasing for chlorophyll *a*, decreasing for turbidity, nitrogen and phosphorus, and there are no trends for nuisance or toxic algae and dissolved oxygen concentrations. SAV coverage is low in the tidal fresh zone and low / medium in the mixing zone where it has an increasing trend.

Physical and Hydrologic Characteristics

Estuarine Drainage Area *(mi^2)* **3,165** Avg. Daily Inflow *(cfs)* **2,942**

	Estuary	Tidal Fresh	Mixing	Seawater
Surface Area *(mi^2)*	**459.3**	**3.6**	**455.7**	**0**
Average Depth *(ft)*	**12.5**	**3.1**	**12.6**	**0**
Volume *(billion cu ft)*	**160**	**0.31**	**160**	**0**

A subsystem to the Chesapeake Bay consisting of two large sounds, smaller bays and broad tidal creeks such as the Nanticoke, Wicomico and the Manokin rivers. The area receives freshwater supply from the Nanticoke River, mainland freshwater runoff, and lateral flow from nearby tidal tidal creeks. During spring flows, salinities tend to be higher in this eastern system than in the western part of the Chesapeake Bay. Tidal range is nearly 2 ft at the south end of Pocomoke Sound to nearly 3 ft within the Wicomico River.

Algal Conditions

	Tidal Fresh		Mixing		Seawater
Chlorophyll *a*	H 50-100%	↑	M ?	↑	
Turbidity	H ?	?	H 10-25%	↓ ?	
Nuisance Algae	?	?	N	– – –	
Toxic Algae	?	?	N	– – –	

Maximum chl-*a* concentrations occur periodically during summer in tidal fresh zone with a limiting factor of light. Maximum concentrations persist throughout the year in the mixing zone with nitrogen as the limiting factor. Maximum turbidity occurs throughout the year.

Ecosystem/Community Responses

	Tidal Fresh		Mixing		Seawater
SAV	L	?	M	↑	

The benthic community is a diverse mixture in tidal fresh zone, and dominated by annelids and mollusks in mixing zone.

Nutrients

	Tidal Fresh		Mixing		Seawater
Nitrogen	H 50-100%	?	M 50-100%	↓	
Phosphorus	H 50-100%	?	M 50-100%	↓	

Elevated concentrations of TDN occur all year in tidal fresh zone, and January to June in mixing zone. Elevated concentrations of TDP occur throughout the year.

Dissolved Oxygen

	Tidal Fresh		Mixing		Seawater
Anoxia	N	– – –	N	– – –	
Hypoxia	N	– – –	N	– – –	

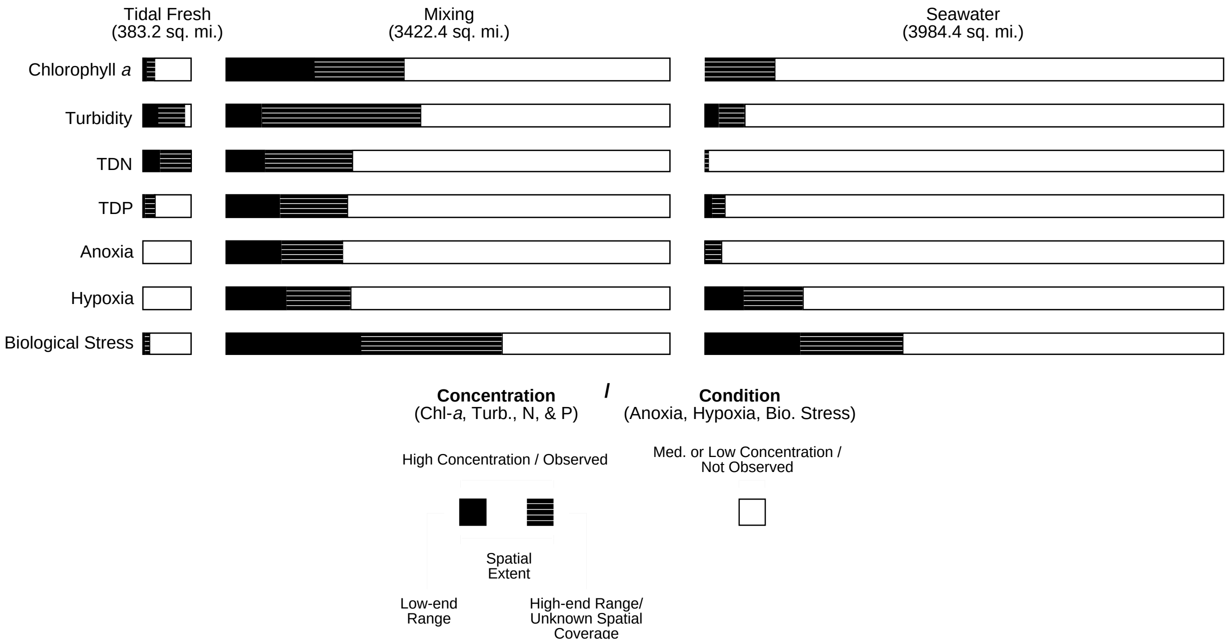
Key on page 21

Regional Summary

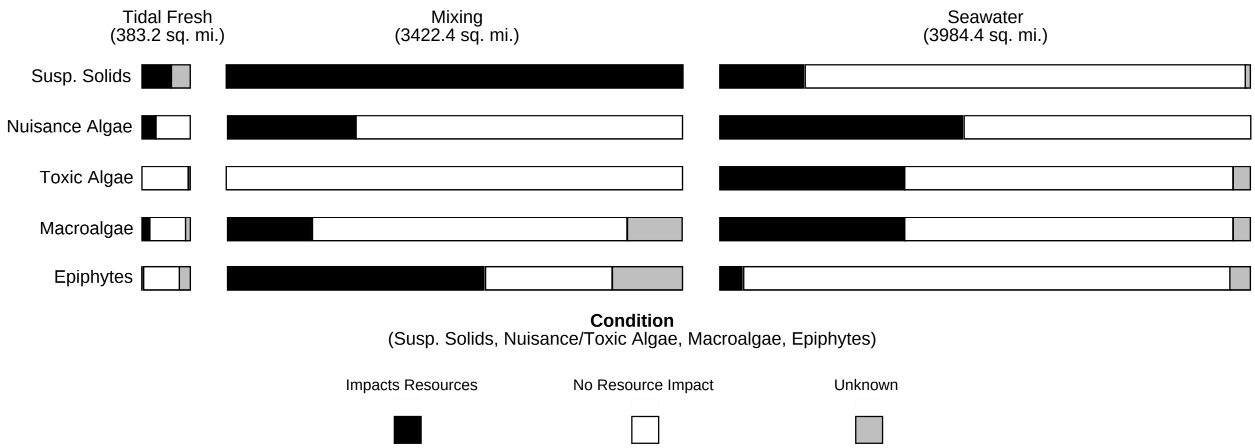
Regional classification status of existing conditions for 12 parameters as a cumulative percentage of total estuarine surface area for three salinity zones.

The spatial extent of existing conditions was recorded, when available, for each salinity zone in each estuary when indicators were recorded at their maximum thresholds (i.e., when chl-*a* was recorded as hypereutrophic, when turbidity, nitrogen, or phosphorus were recorded as high, and when anoxia, hypoxia, or biologically stressed oxygen conditions were observed). Four ranges were used: high (51%-100% of the surface area in a salinity zone), medium (26%-50%), low (10%-25%), and very low (1%-10%).

The figure represents a method for quantifying these results. Black shows conservative estimates of cumulative spatial extent (e.g., high spatial extent equals 51% of an estuary's surface area). Black with white lines shows liberal estimates (e.g., high equals 100% and unknown spatial coverage also equals 100%). White shows the cumulative total surface area reported to have low concentrations or no observed conditions.



The presence of suspended solids, nuisance algae, toxic algae, macroalgae, and epiphytes in each salinity zone were reported as either impacting resources, not impacting resources, or unknown. The spatial extent of these conditions was not recorded.



Appendix 1: Participants

The persons below supplied the information included in this report. Survey participants provided the initial data to ORCA via survey forms sent through the mail. Site visit participants provided additional data through on-site interviews with project staff. These persons also reviewed initial survey data where available. Workshop participants reviewed and revised, in a workshop setting, preliminary aggregate results and, where possible, provided additional data that was still missing. All participants also had the opportunity to provide comments and suggestions on the estuary salinity maps.

Mid-Atlantic Regional Workshop (January 18-19, 1995 Silver Spring, MD)

Thomas Brosnan	New York City Department of Environmental Protection
Claire Buchanon	Potomac River Basin Commission
Bob Connel	New Jersey Department of Environmental Protection
Sherri Cooper	Mid-Atlantic Marine Research Program
David L. Correll	Smithsonian Environmental Research Center
Elizabeth M. Cosper	State University of New York
Donald Heinle	CH2M Hill
Frederick A. Hoffman	Virginia Department of Environmental Quality
Fred Holland	South Carolina Department of Wildlife & Marine Resources
Robert Magnien	Maryland Department of the Environment
Tom Malone	University of Maryland - Horn Point Environmental Laboratory
Robert Nuzzi	Suffolk County, New York Department of Health Services
John F. Paul	U.S. Environmental Protection Agency
Louis E. Sage	Academy of Natural Sciences
Paul Stacey	Connecticut Department of Environmental Protection

Survey/Site Visits

* participated in site visit
• participated in survey and site visit

Buzzards Bay

Anne E. Giblin	Marine Biological Laboratory
John F. Paul	U.S. EPA
Frederick T. Short	Univ. of New Hampshire
Jefferson Turner	Univ. of MA - Dartmouth

Central Buzzards Bay

Joseph Costa*	Buzzards Bay Project

Buzzards Bay Embayments

Joseph Costa*	Buzzards Bay Project

Narragansett Bay

Christopher R. DeAcutis	RI Dept. of Env. Mgmt.
Peter H. Doering	Univ. of Rhode Island
Marilyn M. Harlin	" " " "
Grace Klein-MacPhee	" " " "
James T. Maughan	CH2M Hill
Candace A. Oviatt	Univ. of Rhode Island
John F. Paul	U.S. EPA
Frederick T. Short	Univ. of New Hampshire
Theodore J. Smayda	Univ. of Rhode Island
Chris Turner	RI Dept. of Env. Mgmt.
Gary H. Wikfors	NOAA

Gardiners Bay

Elizabeth M. Cosper	State Univ. of New York
Robert Nuzzi	Suffolk Co. Dept. of Hlth. Ser.
John F. Paul	U.S. EPA

Long Island Sound

Josephine Aller	SUNY at Stony Brook
Harry Bokuniewicz	" " " "
Thomas M. Brosnan	NY City Dept. of Env. Prot.
Jim Citak	Connecticut Dept. of Ag.
Elizabeth M. Cosper	State Univ. of New York
Howard Golub	Interstate Sanitation Comm.
James T. Maughan	CH2M Hill
Doreen M. Monteleone	NY State Dept. of Econ. Dev.
Christine Olsen	Conn. Dept. of Env. Prot.
Jay E. O'Reilly	NOAA
John F. Paul	U.S. EPA
David Simpson	Conn. Dept. of Env. Prot.
Malcolm Shute	Connecticut Dept. of Ag.
Paul Stacey •	Conn. Dept. of Env. Prot.
R. Lawrence Swanson	SUNY at Stony Brook
Robert B. Whitlatch	University of Connecticut
Gary H. Wikfors	NOAA
Charles Yarish	University of Connecticut

Connecticut River

Juliana Barret	Nature Conservancy
Jim Foerth	Yankee Atomic Power Plant
Jon Morrison*	U.S. Geological Survey
John F. Paul	U.S. EPA
Ernest Pizzuto*	Conn. Dept. of Env. Prot.
Paul Stacey*	" " " "
Elaine Trench*	U.S. Geological Survey
Gary H. Wikfors	NOAA

Great South Bay

Elizabeth Cosper	State Univ. of New York
Doreen M. Monteleone	NY State Dept. of Econ. Dev.
Robert Nuzzi	Suffolk Co. Dept. of Hlth. Serv.
John F. Paul	U.S. EPA

Hudson River/Raritan Bay

Sima Bagheri	NJ Institute of Technology
Jordan Clark	Columbia University
Bob Connel	NJ Dept. of Env. Protection
Thomas M. Brosnan	NY City Dept. of Env. Prot.
Jonathan J. Cole	Institute of Ecosystem Studies
Howard Golub	Interstate Sanitation Comm.
John F. Paul	U.S. EPA
Carl J. Sindermann	Oxford Laboratory
R. Lawrence Swanson	SUNY at Stony Brook
James P. Thomas	NOAA

Barnegat Bay

Bob Connel*	NJ Dept. of Env. Protection
Bill Eisle*	“ “ “ “
Sandy Groppenbucher*	“ “ “ “
Al Korndoerhfer*	“ “ “ “
James Mumman*	“ “ “ “
Paul Olsen*	“ “ “ “
John F. Paul	U.S. EPA
Sybil P. Seitzinger	Rutgers University

New Jersey Inland Bays

Bob Connel*	NJ Dept. of Env. Protection
Bill Eisle*	“ “ “ “
Sandy Groppenbucher*	“ “ “ “
Al Korndoerhfer*	“ “ “ “
James Mumman*	“ “ “ “
Paul Olsen*	“ “ “ “
John F. Paul	U.S. EPA

Delaware Bay

Richard Albert	DE River Basin Comm.
Robert B. Biggs	Roy F. Weston Inc.
Bob Connel*	N.J. Dept. of Env. Protection
James Mumman*	“ “ “ “
John F. Paul	U.S. EPA
Jonathan Pennock	University of Alabama
Louis E. Sage	Academy of Natural Sciences
Jonathan Sharpe	University of Delaware

Delaware Inland Bays

Charles App	U.S. EPA
Carl F. Cerco	U.S. Army Corps. of Engineers
Robert J. Orth	College of William and Mary
John F. Paul	U.S. EPA
Kent S. Price	University of Delaware
Sybil P. Seitzinger	Rutgers University
Jonathan Sharpe	University of Delaware
Steve Weisberg*	Versar Inc.

Maryland Inland Bays

Walter Boynton	Chesapeake Biological Lab.
Nick Carter	MD Dept. of Nat. Resources
James F. Casey	“ “ “ “
Tom Malone	University of Maryland
Diana Domotor	MD Dept. of the Environment
Steve Weisberg*	Versar Inc.

Chincoteague Bay

Diana Domotor	MD Dept. of the Environment
Tom Malone	University of Maryland
John F. Paul	U.S. EPA
Steve Weisberg*	Versar Inc.

Chesapeake Bay

Charles App	U.S. EPA
Robert B. Biggs	Roy F. Weston Inc.
Denise Breitburg	Academy of Natural Sciences
Carl F. Carco	U.S. Army Corps. of Engineers
John E. Cooper	East Carolina University
Sherri Cooper	Mid-Atl. Reg. Mar. Res. Prog.
David L. Correll	Smithsonian Env. Res. Cntr.
Deborah Tan Everitt*	MD Dept. of the Environment
Don Heinle	CH2M Hill
Fred Holland	SC Dept. of Wild. & Mar. Res.
Stephen J. Jordan	MD Dept. of Nat. Resources
Robert Magnien	MD Dept. of the Environment
Tom Malone	
Bruce Michael*	University of Maryland
John F. Paul	U.S. EPA
Ananda Ranasinghe	Versar Inc.
Carl J. Sindermann	Oxford Laboratory
Robert Thomann	Manhattan College
Steve Weisberg*	Versar Inc.

Patuxent River

Robert B. Biggs	Roy F. Weston Inc.
David L. Correll	Smithsonian Env. Res. Cntr.
Deborah Tan Everitt*	MD Dept. of the Environment
Don Heinle	CH2M Hill
Fred Holland	SC Dept. of Wild. & Mar. Res.
Stephan J. Jordan	MD Dept. of Nat. Resources
Robert Magnien	MD Dept. of the Environment
John F. Paul	U.S. EPA
Ananda Ranasinghe	Versar Inc.
Louis E. Sage	Academy of Natural Sciences
James G. Sanders	Benedict Estuarine Res. Lab.

Potomac River

Claire Buchanon*	Interstate Comm. on the Pot.
Sherri Cooper	Mid-Atl. Reg. Mar. Res. Prog.
Deborah Tan Everitt*	MD Dept. of the Environment
Don Heinle	CH2M Hill
Fred Holland	SC Dept. of Wild. & Mar. Res.
Norbert Jaworski	U.S. EPA
Robert Magnien	MD Dept of the Environment
Bruce Michael*	“ “ “ “
John F. Paul	U.S. EPA
Ananda Ranasinghe	Versar Inc.
Louis E. Sage	Academy of Natural Sciences
Steve Weisberg*	Versar Inc.

Rappahannock River

Robert J. Diaz*	VIMS
Frederick A. Hoffman	VA Dept. of Env. Quality
John F. Paul	U.S. EPA
Steve Weisberg*	Versar Inc.

York River

Robert J. Diaz*	VIMS
Frederick A. Hoffman	VA Dept. of Env. Quality
John F. Paul	U.S. EPA
Valerie Shaffer*	VIMS
Steve Weisberg*	Versar Inc.

James River

Frederick A. Hoffman	VA Dept. of Env. Quality
John F. Paul	U.S. EPA
Steve Weisberg*	Versar Inc.

Chester River

David L. Correll	Smithsonian Env. Res. Cntr.
Deborah Tan Everitt*	MD Dept. of the Environment
Don Heinle	CH2M Hill
Robert Magnien	MD Dept. of the Environment
Bruce Michael*	" " " "
John F. Paul	U.S. EPA
Ananda Ranasinghe	Versar Inc.
J. Court Stevenson	University of Maryland
Steve Weisberg*	Versar Inc.

Choptank River

David L. Correll	Smithsonian Env. Res. Cntr.
Deborah Tan Everitt*	MD Dept. of the Environment
Thomas Fisher	Horn Point Env. Lab
Don Heinle	CH2M Hill
Tom Jones	Salisbury State University
Stephen J. Jordan	MD Dept. of Nat. Resources
Robert Magnien	MD Dept. of the Environment
Tom Malone	University of Maryland
John F. Paul	U.S. EPA
Ananda Ranasinghe	Versar Inc.
Carl J. Sindermann	Oxford Laboratory

Tangier/Pocomoke Sound

Robert J. Diaz*	VIMS
Deborah Tan Everitt*	MD Dept. of the Environment
Don Heinle	CH2M Hill
Tom Jones	Salisbury State University
Stephen J. Jordan	MD Dept. of Nat. Resources
Robert Magnien	MD Dept. of the Environment
Bruce Michael*	" " " "
John F. Paul	U.S. EPA
Steve Weisberg*	Versar Inc.

Appendix 2: Estuary References

The following references were recommended by one or more Eutrophication Survey participants as critical background material for understanding the nutrient enrichment characteristics of individual Mid-Atlantic estuaries. In some cases, the survey results are based directly upon these publications. This list is not comprehensive; some estuaries are not included because no suggestions were received.

Gardiners Bay

Cashin Associates. 1996. Peconic Estuary Program Final Submerged Aquatic Vegetation Study. Suffolk County Department of Health Services, Suffolk County, NY

Suffolk County Department of Health Services. 1992. Brown Tide Comprehensive Assessment and Management Program (Vol. 1-3 and Summary). Suffolk County, NY.

Long Island Sound

Brosnan, T.M. and A.I. Stubin. 1992. Spatial and temporal trends of dissolved oxygen in the East River and Western Long Island Sound. In: *Proceedings of the Long Island Sound Research Conference*. October 23-24, 1992.

Brosnan, T.M. and M.L. O'Shea. 1994. *New York Harbor water quality survey*. Marine Sciences Section, Bureau of Clean Water, NYC Department of Environmental Protection. Wards Island, NY.

HydroQual, Inc. 1996. Water Quality Modeling Analysis of Hypoxia in Long Island Sound Using LIS3.0. Job No. NENG0035. Prepared for the Management Committee of the Long Island Sound Study and New England Interstate Water Pollution Control Commission. July 1996.

HydroQual, Inc. 1995. Analysis of Factors Affecting Historical Dissolved Oxygen Trends in Western Long Island Sound. Job No. NENG0040. Prepared for the Management Committee of the Long Island Sound Study and New England Interstate Water Pollution Control Commission.

Parker, C.A. and J.E. O'Reilly. 1991. Oxygen depletion in Long Island Sound - a historical perspective. *Estuaries.* 14(3):248-264.

Stacey, P. 1990. Conditions in Long Island Sound. In: *Proceedings of cleaning up our coastal waters: An unfinished agenda*. Manhattan College, Riverdale, NY. March 12-14, 1990.

Welsh and Eller. 1991. Mechanisms for controlling summertime oxygen depletion in West Long Island Sound. *Estuaries.* 14: 265-278.

Hudson River/Raritan Bay

Ayres, R.U., and S.R. Rod. 1986. Patterns of Pollution in the Hudson-Raritan Basin. *Environmental Reporter* 28(4): 15-25

Brosnan, T.M. and M.L. O'Shea. 1996. Long-term improvements in water quality due to sewage abatement in the Lower Hudson River. *Estuaries, 19:4*

Clark, J.F., H.J. Simpson, R.F. Bopp and B. Deck. 1992. Geochemistry and loading history of phosphate and silicate in the Hudson estuary. *Estuarine, Coastal, and Shelf Science.* 34:213-233.

Cristini, A.G. 1991. *Synthesis of information on the distribution of benthic invertebrates in the Hudson/Raritan system. Final report.* July 1991.

Malone, T.C. 1982. Factors influencing the fate of sewage-derived nutrients in the Lower Hudson estuary and New York Bight. In: Mayer G.F. (ed.) *Ecological Stress and the New York Bight: Science and Management.* Estuarine Research Federation, Columbia, SC. 1982. pp. 389-400.

O'Connor, D.J. 1990. A Historical Perspective Engineering and Scientific. In: Proceedings of Cleaning Up Our Coastal Waters: An Unfinished Agenda. Manhattan College, Riverdale, NY. March 12-14.

Studholme, A.L. 1987. *An overview of the biological resources of the Hudson/Raritan estuary. Hudson/Raritan estuary: Issues, resources and management.* NOAA Estuary of the Month Seminar Series No. 9. National Oceanic and Atmospheric Administration.

Great South Bay

Bokuniewicz, H. A. McElroy, C. Schlenk and J. Tanski (eds.). 1993. Estuarine Resources of the Fire Island National Seashore and Vicinity. New York Sea Grant, National Oceanic and Atmospheric Administration.

Cosper, E.M., V.M. Bricelj, and E.J. Carpenter (eds.). 1989. Novel phytoplankton blooms, causes and impacts of recurrent brown tides and other unusual blooms, *Coastal and Estuarine Studies* : Springer-Verlag, Berlin.

Durand, J. and R.J. Nadeau. 1972. *Biological evaluation of the Mullica River-Great Bay estuary*. New Brunswick, NJ: Rutgers University, Water Resources Research Institute.

Schubel, J.R., T.M. Bell and H.H. Carter (eds.) 1991. The Great South Bay, State University of New York Press, Albany, NY. 107 pp.

Barnegat Bay

Kennish, M.J. and R.A. Lutz. 1984. *Ecology of Barnegat Bay, New Jersey*. New York: Springer-Verlag.

Delaware Bay

Bryant and Pennock, J. (eds). *The Delaware estuary: Rediscovering a forgotten resource.* University of Delaware Sea Grant Program.

Cooper, S.R. and D. Lipton. 1994. *Mid-Atlantic Research Plan: Mid Atlantic Regional Marine Research Program*. University of Maryland, 2200 Summons Hall, College Park, MD. 163 pp.

Marshall, H.G. 1992. *Assessment of phytoplankton species in the Delaware River estuary*. Norfolk, Virginia: Old Dominion University.

Pennock, J. 1985. Chlorophyll distribution in the Delaware estuary: Regulation by light limitation. *Estuarine, Coastal, and Shelf Sci.* 21: 711-725.

Pennock, J. and Sharp, J. (eds.). 1986. *Marine Ecol. Prog. Series.* 34: 143-155.

Taft, J.L. and W.R. Taylor. 1976. Phosphorus dynamics in some coastal plain estuaries. pp. 78-89. In: M. Wiley (ed.), Estuarine Processes, Volume 1. Uses, Stresses, and Adaptation to the Estuary. Academic Press, New York, N.Y.

Delaware Inland Bays

Cooper, S.R. and D. Lipton. 1994. *Mid-Atlantic Research Plan: Mid Atlantic Regional Marine Research Program*. University of Maryland, 2200 Summons Hall, College Park, MD. 163 pp.

Chesapeake Bay

Boynton, W.R., J.H. Garber, R. Summers, and W.M. Kemp. (1995) Inputs, transformations and transport of nitrogen and phosphorous in Chesapeake Bay and selected tributaries. *Estuaries*. 18 (1B): 285-314.

Brush, G.S. 1994. Human impact on estuarine ecosystems: an historical perspective. In: N. Roberts (ed.), Global Environmental Change: Geographical Perspectives. Blackwell Publishing Co.: 397-416

Brush, G.S. 1984. Stratigraphic evidence of eutrophication in an estuary. *Water Resources Research* 20(5): 531-541.

Brush, G.S. and F.W. Davis. Stratigraphic evidence of human disturbance in an estuary. *Quaternary Research* 22:91-108.

Cooper, S.R 1995. Chesapeake Bay watershed historical land use: Impacts on water quality and diatom communities. *Ecol. App. 5(3): 703-723.*

Cooper, S.R. and D. Lipton. 1994. *Mid-Atlantic Research Plan: Mid Atlantic Regional Marine Research Program*. University of Maryland, 2200 Symons Hall, College Park, MD. 163 pp.

Cooper, S.R. and G.S. Brush. 1993. A 2,500 year history of anoxia and eutrophication in Chesapeake Bay. *Estuaries* 16(3B): 617-626.

Cooper, S.R. and G.S. Brush. 1991. Long-term history of Chesapeake Bay anoxia. *Science*. 254: 992-996.

Cornwell, J.C., D.J. Conley, M. Owens, and J.C. Stevenson. 1996. A sediment chronology of the eutrophication of Chesapeake Bay. IN: S.B. Bricker and J.C. Stevenson (eds.) *Estuaries* 19(2B): 488-499.

Correll, D.L. 1987. Nutrients in Chesapeake Bay. 298-320 In: S.K. Majumdar, L.W. Hall, Jr. and H.M. Austin (eds.). *Contaminant Problems and Management of Living Chesapeake Bay Resources*. Penn. Acad. Sci., Philadelphia, PA.

Correll, D.L. 1981. Eutrophication trends in the water quality of the Rhode River (1971-1978). 425-435 In: B.J. Neilson and L.E. Cronin (eds.). *Estuaries and Nutrients*. Humana Press, Clifton, NJ.

Correll, D.L., Jordan, T.E., and D.E. Weller. 1992. Nutrient flux in a landscape: Effects of coastal land use and terrestrial community mosaic on nutrient transport to coastal waters. *Estuaries.* 15:431-442.

D'Elia, C.F. 1987. Nutrient enrichment of the Chesapeake Bay. *Environment* 29(12): 6-11, 30-33.

D'Elia, C.F., L.W. Harding, M. Leffler, and G.B. Mackiernan. 1992. The role and control of nutrients in Chesapeake Bay. *Wat. Sci. Tech.* 26(12(: 2635-2644.

Gallegos, C.L., Correll, D.L., and Pierce, J.W. 1990. Modeling spectral diffuse attenuation, absorption, and scattering coefficients in a turbid estuary. *Limnol. Oceanogr.* 35:1486-1502.

Harding, L.W. 1994. Long-term trends in the distribution of phytoplankton in Chesapeake Bay: roles of light, nutrients and stream flow. *Mar. Ecol. Prog. Ser.* 104:267-291.

Heinle, D'Elia, Taft, Wilson, Cole-Jones, Caplins, Cronin. 1980. *Historical review of water quality and climatic data from Chesapeake Bay of effects of enrichment.* CRC Publication No. 84.

Jordan, T.E., Correll, D.L., J. Miklas, and D.E. Weller. 1991. Nutrients and chlorophyll at the interface of a watershed and an estuary. *Limnol. Oceanogr.* 36:251-267.

Jordan, T.E., Correll, D.L., J. Miklas, and D.E. Weller. 1991a. Long-term trends in estuarine nutrients and chlorophyll, and short-term effects of variation in watershed discharge. *Mar. Ecol. Prog. Ser*. 75: 121-132.

Malone, T.C., D.J. Conley, T.R. Fisher, P.M. Glibert, L.W. Harding, and K.G. Sellner. Scales of nutrient-limited phytoplankton productivity in Chesapeake Bay. In: S.B. Bricker and J.C. Stevenson (eds.). *Estuaries*. 19(2B): 371-385.

Smith, Leffler, and Mackiernan. 1992. *Oxygen dynamics in Chesapeake Bay: A synthesis of recent research.* Maryland Sea Grant College Program.

Taft, J.L. and W.R. Taylor. 1976. Phosphorus dynamics in some coastal plain estuaries. pp. 78-89. In: M. Wiley (ed.), Estuarine Processes, Volume 1. Uses, Stresses, and Adaptation to the Estuary. Academic Press, New York, N.Y.

Patuxent River

Heinle, D'Elia, Taft, Wilson, Cole-Jones, Caplins, Cronin. 1980. *Historical review of water quality and climatic data from Chesapeake Bay of effects of enrichment*. CRC Publication No. 84.

Kemp, W.M. and W. R. Boynton. 1984. Spatial and temporal coupling of nutrient imputs to estuarine primary production: the role of particulate transport and decomposition. *Bulletin of Marine Science* 35(3): 522-535.

Taft, J.L. and W.R. Taylor. 1976. Phosphorus dynamics in some coastal plain estuaries. pp. 78-89. In: M. Wiley (ed.), Estuarine Processes, Volume 1. Uses, Stresses, and Adaptation to the Estuary. Academic Press, New York, N.Y.

Potomac River

Champ, M. A., O. Villa, and R.C. Bubeck. 1980. H*istorical overview of the freshwater inflow and sewage treatment plant discharges to the Potomac River Estuary with resultant nutrient and water quality trends.* NOAA / RD, Office of Marine Pollution Assessment, Rockville, MD.

Jones, R., Christian, Kelso, Donald. 1993. *An ecological study of Gunston Cove 1992-93.* Department of Public Works, County of Fairfax, Fairfax, Virginia.

James River

Heinle, D'Elia, Taft, Wilson, Cole-Jones, Caplins, Cronin. 1980. *Historical review of water quality and climatic data from Chesapeake Bay of effects of enrichment.* CRC Publication No. 84.

Choptank River

Stevenson, J.C., L.W. Staver, and K.W. Staver. 1993. Water quality associated with survival of submersed aquatic vegetation along an estuarine gradient. *Estuaries.* 16: 346-361.

Appendix 3: NEI Estuaries

One hundred twenty-nine estuaries are included in the National Estuarine Inventory. New systems are occassionaly added. Some estuaries are actually sub-systems of larger estuaries although each is being evaluated indepedently for the Eutrophication Survey project (e.g. Potomac River is a sub-system of Chesapeake Bay). For more information on the National Estuarine Inventory, see inside the front cover of this report.

North Atlantic (16)

Passamaquoddy Bay
Englishman Bay
Narraguagus Bay
Blue Hill Bay
Penobscot Bay
Muscongus Bay
Damariscotta River
Sheepscot Bay
Kennebec/Androscoggin Rivers
Casco Bay
Saco Bay
Great Bay
Merrimack River
Massachusetts Bay
Boston Bay
Cape Cod Bay

Mid Atlantic (22)

Buzzards Bay
Narragansett Bay
Gardiners Bay
Long Island Sound
Connecticut River
Great South Bay
Hudson River/Raritan Bay
Barnegat Bay
New Jersey Inland Bays
Delaware Bay
Delaware Inland Bays
Maryland Inland Bays
Chincoteague Bay
Chesapeake Bay
Patuxent River
Potomac River
Rappahannock River
York River
James River
Chester River
Choptank River
Tangier/Pocomoke Sounds

South Atlantic (21)

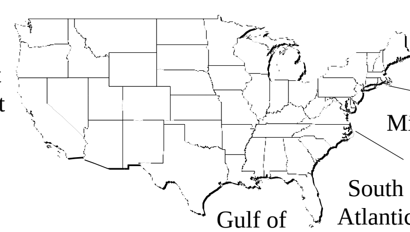
Albemarle/Pamlico Sounds
Pamlico/Pungo Rivers
Neuse River
Bogue Sound
New River
Cape Fear River
Winyah Bay
North/South Santee Rivers
Charleston Harbor
Stono/North Edisto Rivers
St. Helena Sounds
Broad River
Savannah River
Ossabaw Sound
St. Catherines/Sapelo Sounds
Altamaha River
St. Andrew/St. Simons Sounds
St. Marys R./Cumberland Snd
St. Johns River
Indian River
Biscayne Bay

Gulf of Mexico (36)

Florida Bay
South Ten Thousand Islands
North Ten Thousand Islands
Rookery Bay
Charlotte Harbor
Caloosahatchee River
Sarasota Bay
Tampa Bay
Suwannee River
Apalachee Bay
Apalachicola Bay
St. Andrew Bay
Choctawhatchee Bay
Pensacola Bay
Perdido Bay
Mobile Bay
Mississippi Sound
Lake Borgne
Lake Pontchartrain
Breton/Chandeleur Snds
Mississippi River
Barataria Bay
Terrebonne/Timbalier Bays
Atchafalaya/Vermilion Bays
Mermentau Estuary
Calcasieu Lake
Sabine Lake
Galveston Bay
Brazos River
Matagorda Bay
San Antonio Bay
Aransas Bay
Corpus Christi Bay
Upper Laguna Madre
Baffin Bay
Lower Laguna Madre

West Coast (34)

Tijuana Estuary
San Diego Bay
Mission Bay
Newport Bay
San Pedro Bay
Alamitos Bay
Anaheim Bay
Santa Monica Bay
Morro Bay
Monterey Bay
Elkhorn Slough
San Francisco Bay
Cent. San Francisco Bay/
San Pablo/Suisun Bays
Drakes Ester
Tomales Bay
Eel River
Humboldt Bay
Klamath River
Rogue River
Coos Bay
Umpqua River
Siuslaw River
Alsea River
Yaquina Bay
Siletz Bay
Netarts Bay
Tillamook Bay
Nehalem River
Columbia River
Willapa Bay
Grays Harbor
Puget Sound
Hood Canal
Skagit Bay



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